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EDITORIAL

OF MAKING MANY PUBLICATIONS

EACH profession has its stock of occupational complaints and laments. Architects and pickpockets bewail the revival of the past. Painters and politicians deplore misinterpretation by the public. Engineers and civil servants bemoan the bigger salaries given elsewhere. The people who work with publications have a lament too, the lament of Ecclesiastes twenty-two centuries ago: "Of making many books there is no end . . .". But it is more than a lament. It is a growing chorus of concern at the phenomenal rate of increase in all printed matter, particularly scientific and technical material. Indeed, many librarians and documentalists are beginning to wonder if the scholar is not in danger of swamping himself in the records of his own ingenuity.

The publications abundance, in aeronautics as elsewhere, would be problem enough if it were only an embarrassment of riches. The difficulties of organizing, housing and finding material are, however, enormously magnified by the surplus of second-rate and repetitious material. Information specialists and librarians are trying to develop storage and retrieval systems to cope with the volume, but they can do little or nothing about the material before it is brought to the public market. Publishers, editors and authors can. Their co-operation is urgently required to bring more order and reason to the present mass and mess.

Journal editors and editorial boards are in a particularly choice position to be of assistance. They have the opportunity to accept or reject. Because they have this opportunity they have also the heavy responsibility of ensuring that the privilege of publication is not abused. This is a difficult task. Sympathetic, fair and competent appraisal must be made of each manuscript. Merit must be demanded and errors pointed out. On the other hand, interference with the author's freedom of expression, in matters of opinion, must be avoided.

If a journal requires that every paper considered for publication must pass the conscientious scrutiny of subject specialists on the editorial board, it cannot lightly be accused of contributing to the surfeit of undistinguished print. This does not mean, of course, that only original work merits acceptance. The competent and comprehensive survey or review of the state of the art needs much more attention from the journals than it is now receiving. The authoritative and critical synthesis, properly documented, is a compact treasure for librarian to pass on to inquirer. For the specialist, it can also be an excellent source of suggestion for further research.

Editors, but perhaps more appropriately, publishers can make still another valuable contribution to efficiency and order in the information process. It is a curious and sad fact that while journals require that manuscripts follow certain reasonable conventions in layout, symbols, references and the like, the journals themselves pursue a chaotic diversity in their make-up. There is a place for artistic individuality, but not in the bibliographic and other features which make for convenient and pleasant use. The scholarly journals have been much less at fault than the trade periodicals, but many are still far from ideal.

There is a further and fundamental contribution which all journal editors and publishers can make to bibliographic sanity. They can ask the question: Is this journal necessary? If, to be honest, the answer must be "No" and if the next step is conscientiously taken, the problem of muchness would be less acute. If, however, the journal is sincerely considered to perform a useful and necessary function, it should then be asked whether the journal should be continued in proud and splendid isolation, or whether both its purpose and the overall purpose of publication might not be better served by amalgamation with another journal. There certainly is an excellent case for the healthy and independent existence of many rewarding journals, as well as for the creation of some new journals, such as the Canadian Aeronautical Journal, which fills a special and definite need. It is equally certain, however, that the proliferation of journals and trade periodicals in many areas of human endeavour is an inefficient, expensive and frustrating luxury which no one in the information process, from author to reader, can afford.

R. A. KENNEDY
Assistant Librarian (Admin.)
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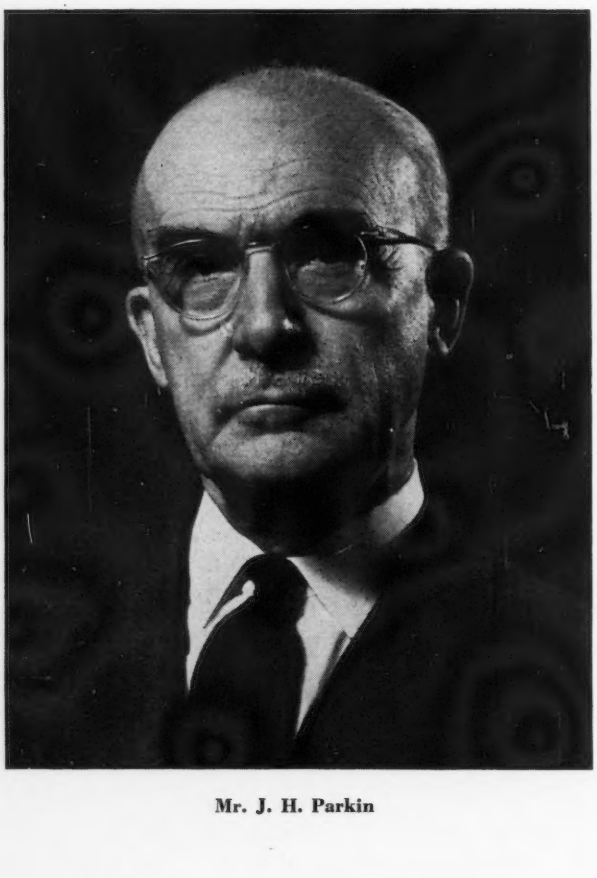
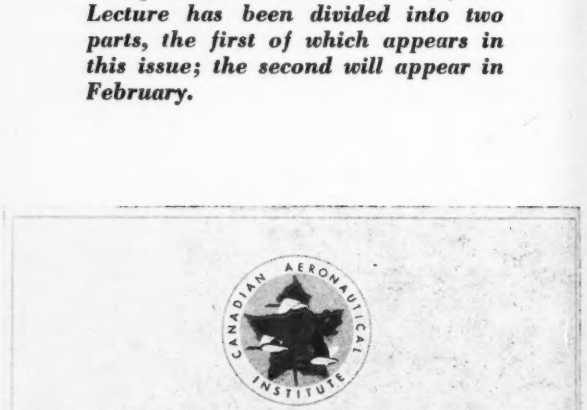
W. RUPERT TURNBULL LECTURER



Mr. J. H. Parkin

Mr. Parkin, Director of the Division of Mechanical Engineering, National Research Council, and Director of the National Aeronautical Establishment delivered the first W. Rupert Turnbull Lecture on the 3rd November 1955. For publication in the Journal, the Lecture has been divided into two parts, the first of which appears in this issue; the second will appear in February.



CANADIAN AERONAUTICAL INSTITUTE

THIS IS PRESENTED TO

John H. Parkin

WHO DELIVERED THE

W. Rupert Turnbull Lecture

for 1955

ON THE OCCASION OF

The International Meeting between the Canadian Aeronautical Institute and the Institute of the Aeronautical Sciences

Held in Ottawa on the 3rd and 4th November 1955.

The Lecture was established in 1955 by the Canadian Aeronautical Institute to commemorate annually the pioneering work in aeronautical engineering carried out by Dr. W. Rupert Turnbull of Rothesay, New Brunswick.

THE SUBJECT OF THIS FIRST LECTURE

WAS

"Wallace Rupert Turnbull 1870-1954"

DATE: 3rd NOVEMBER 1955.

PRESIDENT

SECRETARY

Mr. Parkin was born in Toronto in 1891 and graduated from the University of Toronto in 1912. In the course of his long association with aeronautics, he initiated and planned the first undergraduate course in Aeronautical Engineering at the University of Toronto where, in 1917, he had constructed a wind tunnel and gained a wide reputation from the papers published on the results of his investigations. From 1919 to 1929 Mr. Parkin maintained a private consulting practice before joining the National Research Council. He was appointed Director of the Division of Mechanical Engineering in 1937 and, in addition, has served as Director of the National Aeronautical Establishment since its inception. He is a Canadian member of A.G.A.R.D.

WALLACE RUPERT TURNBULL, 1870-1954

CANADIAN PIONEER OF SCIENTIFIC AVIATION†

by J. H. Parkin*

National Aeronautical Establishment

INTRODUCTION

In the three hundred and fifty years since the establishment of the first permanent settlement, Port Royal, on the mainland of North America, Canada has developed from being a source of raw materials to her present position as an important industrial nation.

During this same period, transportation in Canada, on which the development depended, following first the natural waterways, progressed from the canoe to the steamboat and great lake carriers, and on land, from the forest trails, to primitive roads, railways and the present coast to coast highway and railway networks and finally to air transport.

With the advent of the aeroplane, its peculiar advantages in the overcoming of the great obstacles to our development – distance and terrain—were soon recognized, and it was quickly adopted for what it was, a tool of great mobility and vision, for the development of our vast country.

The aeroplane provided Canada with time, telescoping into decades development requiring centuries in older countries.

Wallace Rupert Turnbull

Canada played a part not only in the utilization of the aeroplane but also in its development. She contributed as well as received. Some of the earliest and most valuable Canadian contributions to the advancement of the new science were those of Wallace Rupert Turnbull, of Rothesay.

It is a strange fact that artificial flight had a fascination for many noted engineers – Wenham, Maxim, Lanchester, Eiffel – and it was so with Turnbull. In many ways Turnbull resembled Wenham,[a] the founder of the Royal Aeronautical Society. Like Wenham, Turnbull was an engineer of many interests, as will be seen, but in whose mind aviation occupied the foremost place.

Turnbull was one of that historic company whose enthusiastic devotion to the promotion of artificial flight and pioneer scientific research, laid the foundation for the science of aeronautics and contributed so much to the sound development of the aeroplane.

Wallace Rupert Turnbull was born at St. John, N.B. on 16 October, 1870. His father, William Wallace Turnbull, of Scotch descent, had come from Bear River in 1847 as a youth of nineteen to St. John to work, and before his death at the age of seventy-one had become a wealthy businessman, banker and philanthropist. Turnbull's mother was Julia Caroline Hatheway whose grandparents left Pennsylvannia in 1783 and settled in the Maugerville district of the St. John River Basin. Turnbull's inheritance from his parents was rich in tradition, achievements and means.

It is probable, if environment shapes one's future, that young Turnbull, watching, on the way home from school, the graceful hulls taking shape in the shipyards

†The First "W. Rupert Turnbull Lecture" read at the I.A.S./C.A.I. International Meeting in Ottawa on the 3rd November, 1955.

*Director

[a]Wenham, 1824-1908, whose interests included marine boilers, air and gas engines, bird flight, photography and various branches of optics and who made the first light gas engine in England and the first applied to aerial navigation.

of St. John, then made up his mind that he too would be a builder, a creater – an engineer.

In due course, in 1889, he entered the School of Mechanical Engineering of Cornell University from which he was graduated in 1893 with the degree of Mechanical Engineer, with electrical engineering as a specialty. The following year he did graduate work in physics and electrical engineering at Cornell but took no graduate degree. Turnbull was one of a group of students who organized the Electrical Society of the University and, at the first meeting, 20 November 1893, was elected Recording Secretary.

On 31 May 1894 Turnbull married Mary Willis Davidson of St. John, the daughter of a prominent lumberman and great grand-daughter of a lumberman who had supplied the Royal Navy with thousands of white pine masts from the forests of New Brunswick. There were four sons of the marriage, William Wallace of South Orange, N.J., Rupert Davidson who died in 1950, Donald Orton of Rothesay and Hugh Hatheway, Q.C., of Montreal.

HIS EARLY WORK

Immediately following their marriage, Mr. and Mrs. Turnbull left for Germany where they stayed some twelve months, and Turnbull did graduate work in physics at Heidelburg during the summer and Berlin during the winter. They returned to Canada 6 June, 1895 and Turnbull spent the next fifteen months regaining his health, afterwards spending the fall term, September to December 1896 on further graduate work on light at Cornell.

Turnbull served as an experimental engineer in the Edison Lamp Works (General Electric Company) at Harrison, N.J. from January 1897 until 1901 when he resigned because of poor health.

While at Cornell he presented, on 9 April 1894, a paper[1] on high speed electric railroading to the Electrical Society he had helped organize, in which he reviewed the possibilities of high speed – say 150 mph – railroading and in which he proposed a revolutionary scheme for a "pneumo-electric" railway. In collaboration with C. H. Sharp, he carried out, during his graduate year an investigation of light standards, using a bolometer, the results of which were published in the Physical Review in 1894[2]. He and Sharp appear also to have designed a spectrophotometer while at Cornell.

During his period with the General Electric Company he published several articles in the technical periodicals related to his work, including one on an effect of a fluorescent substance on the cathode and x-rays[3]. In this connection it may be mentioned that he handled the first Roentgen ray tubes that were shipped from Germany to this country. Another article published at this time (1897) dealt with the composition of light from different sources and the meaning of the term "luminosity"[4].

In 1901 Turnbull returned permanently to Rothesay, and set up as a consulting engineer, his letterhead reading, "W. R. Turnbull, M.E., Consulting Engineer, Laboratory, Rothesay, New Brunswick, Canada". Later, he was to add to this letterhead "Specialties: Variable Pitch Air Propellers, Consolidated Wood, Internal Combustion Motors".

AERONAUTICS

About 1900 Turnbull had become interested in aeronautical research, mostly as a result of the work of Lilienthal and Langley, and, on his return to Rothesay began active research.

From his study of aeronautics, even at that early date, Turnbull was most firmly convinced that the aeroplane was on its way and that actual flight would soon be a reality. However, caution was necessary and Mrs. Turnbull implored him to let no one know what he was working on or he would be taken for a "flying machine crank".

In after years he could look back with amusement to those "great days" when the poor pioneer laboured under tremendous disadvantages and against great prejudice to accomplish a little useful "spade work".

In 1902 he began operations in Anderson's Barn in Rothesay Park, a small wooded peninsula in a beautiful stretch of the Kennebecasis River. The barn was a two-storey frame building about 28 x 40 feet and provided Turnbull with some 2,200 sq. ft. of floor space. Here he set up a modest shop on the ground floor, and laboratory above. Power was supplied from a gasoline engine driven dynamo and fifty-five cell storage battery.

The barn, which is still in existence, has had a varied career as barn, dance hall, workshop and dwelling.

By 1906 his work demanded more space and he acquired Fraser's Barn located in the central part of the Village of Rothesay. This was a three-storey frame structure, about 26 x 40 feet, with about 3,100 sq. ft. of working space. The period 1906-1914, during which he used Fraser's Barn, was probably the period of Turnbull's greatest research activity. It saw him working on propellers, lift devices, internal combustion engines and turbines and hydroplanes.

In 1914 the barn was moved some one thousand feet and incorporated in the residence he was building and which was still the family home at the time of his death. At the same time he built, adjacent to the house, a new, smaller workshop of single storey frame construction, 12 x 24 feet, to which an Annex 13 x 24 feet of similar construction was added in 1919. In these he had a small shop equipped with bench and power tools, drill, lathe and the like, and another room serving as library and drafting room, adequate for the reduced scale of his operations.

THE FIRST WIND TUNNEL IN CANADA

The first wind tunnel in Canada was built by Turnbull in Anderson's Barn in 1902. He could not recall where he got the idea for a wind tunnel but thought possibly it was from Stanton who had built and used an air channel in England in 1902[5]. However, it seems doubtful if the idea could have come from Stanton, not only because of the date, but because Turnbull's tunnel differed from Stanton's in many ways. Stanton's was cylindrical, vertical, the air was drawn through the tunnel[b] and the measuring apparatus was in a closed box surrounding a gap in the tunnel.

The idea may possibly have come from the Wright brothers although they had published nothing at that

[b]Sokolov had discovered that aspiration produced a smoother air current.

SCIENTIFIC AMERICAN SUPPLEMENT, 16 Oct. 1909, p. 244.

time. The brothers had, in the fall of 1901, built a makeshift wind tunnel, which, having demonstrated its value, was followed in a month or so by an improved tunnel, which Turnbull's tunnel resembled in several particulars. A two-bladed belt driven fan discharged air through a screen and honeycomb into a 16-inch square tube six feet long[6].

Only two other wind tunnels had been built in America before Turnbull's, one by A. J. Wells[7] at the Massachusetts Institute of Technology to verify Langley's results and described in a thesis submitted 17 November 1896 and the other by Albert F. Zahm[8] at the Catholic University, Washington, in the spring of 1901 and used in the determination of surface friction on thin plates.

The earliest wind tunnel, of which there is record, was that of Wenham, in England in 1871[9]. Turnbull's tunnel anti-dated those of many whose names are prominent in the literature of aeronautical research including, Riabouchinsky 1904[10], Prandtl 1908[11] and Eiffel 1909[12]. Lilienthal[13], Langley[14] and Dines[15] had used whirling arms.

In commencing his aeronautical experiments Turnbull recognized that a uniform constant wind was essential and further that this condition was impossible in a natural wind and difficult to attain in an artificial wind. He therefore adopted the wind tunnel to insure a "constant" air current and that his results would be "exactly comparable" with one another.

The tunnel proper[16] was a rectangular wooden box 22 inches square and 6 feet long, mounted two feet above the floor on trestles. At one open end (the "wrong" end) a heavy four-bladed wooden propeller fan was mounted, belt driven by a one-half horsepower series wound motor supplied from the 110-volt storage battery. The fan discharged air into the box where thin diagonal and transverse baffle plates, occupying about half the length of the box, removed the propeller whirl and the air issued from the other, the experimental, end of the box as a practically rectilinear jet.

The elevation of the tunnel above the floor was most important to insure uniformity in the issuing jet.

The speed of the fan was so adjusted that the air current issuing from the tunnel had a speed of exactly 10 mph at a distance of one foot from the end of the box.

To measure the air velocity Turnbull made an inclination anemometer based on data published in the Handbuch der Physik[c].

AEROPLANE STABILITY

From a careful study of the history of "aerodynes" Turnbull was impressed by the fact that every machine both tried and untried, was lacking, in some cases wholly, in automatic longitudinal stability, although possessing fairly satisfactory automatic transverse stability provided by keels or dihedral angle of the wings.

For this reason, his first investigation was one seeking an "aeroplane" possessing automatic longitudinal stability.

In a letter to the Scientific American dated 8 September 1906[17] Turnbull had questioned the terminology of the International Aeronautical Congress of 1889 with respect to the term aeroplane. He contended that the science was developing very rapidly and that the state of the art warranted a new term to replace aeroplane as designating a complete machine, one of the three subdivisions of aeronef or flying machine. He believed that an aeroplane could only be one of the parts of the complete machine, i.e. the wing. He considered Langley's term aerodrome euphonious, but Captain Ferber had pointed out that aerodrome really meant an air course and, in France, also designated a balloon shed. Turnbull proposed the term aerodyne to denote an "aeroplane supported machine driven by mechanical power".

Turnbull's original experiments were made in February-April 1905 (the first records in his "curve" book are dated 30 March 1905) and were repeated with refined apparatus in June and July 1906. The results were published in a paper dated 10 October 1906[16].

Five aerofoils were tested, made of thin tin plate stiffened with three ribs on the upper side, having an area of practically ten square inches and an aspect ratio of 2 (8.485 x 16.97 inches). To make the study systematic five profiles were used, one a flat plate, two of single curvature, convex and concave respectively on the under side, and two of double curvature, one concave forward and convex aft on the under side and the other convex forward and concave aft.

A simple balance arm mounted, in horizontal pivots, one foot from the end of the tunnel, was used to measure the lift of the aerofoils over an incidence range of 0° to 20°.

Turnbull measured the lift and drift, the vertical and horizontal components of the air reaction, rather than plotting the resultant force from lift and drift and resolving the resultant into normal and tangential forces as had Lilienthal. Turnbull considered Lilienthal's method applicable only to flight with flapping wings and not to flight with fixed aerofoils.

For the determination of drift, the balance arm was mounted in vertical pivots and the scale pan hung on a cord passing over a frictionless pulley from the arm.

Turnbull concluded, after tests, that the separate determination of lift and drift was more sensitive and accurate than a compound balance as used by Maxim.

Lilienthal in his experiments had passed too lightly over the question of centre of pressure and Joessel[18], Kummer[19] and Langley had stopped short of the normal flight range 0° to 25°. Turnbull covered the range from 0° to 90° or over and, while using Langley's method, a dead weight to balance the pitching moment about pivots at the ends of the model, he substituted a delicate calibrated spring for the weight for the models whose c.p. advanced far ahead of their geometric centre. When both methods were applicable he found the "accordance" of the readings satisfactory.

The results of his experiments showed that the c.p. of the flat, concave and convex-concave aerofoils moved rapidly forward with increasing incidence, to a critical angle about 26° to 30° and thereafter moved slowly aft to 90°. Turnbull concluded that this reversal of travel resulted in an utter lack of longitudinal stability and he attributed the many accidents, including that to Langley's machine, and the deaths of Lilienthal and Pilcher, to the lack of knowledge of this characteristic.

[c] *Mechanik und Akustik.* Winkelmann, v. 1, p. 564.

The convex, and concave-convex models, on the other hand, showed a continuous rearward movement of the c.p. as the incidence increased from 0° to 90° and he concluded that these two models had "automatic longitudinal stability for all positive angles and lifts".

Analysing his results from the viewpoint of artificial flight, Turnbull concluded that while the concave aerofoil which had been used, almost exclusively up to that time, in aeroplanes, was attractive from a lift standpoint, it had also a relatively high drift and lacked stability. Comparing the concave with his concave-convex on a basis of lift for equal drift (thus approaching the concept of L/D) he found that the aerofoil of double curvature at 10° had twice the lift of the concave at – 0.7°.

Turnbull concluded that the concave-convex aerofoil provided "the essential elements of automatic longitudinal stability; the well established principles of the 'dihedral angle' and the keel give automatic transverse stability; and gas engines, now approaching 3 lb./hp. give the required lightness of prime movers.

"In these three principles therefore the problem of aerial navigation is theoretically solved. It now remains only to so combine these three essentials, in practical form, to solve the problem from an engineering standpoint."

Turnbull, in thus summing up the matter as an engineer, did not claim that aerofoils of this type were the only ones possessing automatic longitudinal stability, but did claim that among simple aerofoils having zero, single or double curvature, his experiments had shown the concave-convex profile only possessed automatic longitudinal stability combined with excellent lift and exceedingly small drift at all angles in the useful flight range.

During these experiments, in 1906 Turnbull visited Alexander Graham Bell at Baddeck, N.S. Bell at the time was seeking, like Turnbull, automatic stability in aeroplanes, but was attempting to limit the c.p. movement by using many small surfaces, in the form of tetrahedral cells (which also possessed structural advantages). Turnbull immediatly saw the impracticability of this course because of the excessive drift.

Turnbull obtained in 1906 a very broad patent[d] on the double curvature aerofoil or hydrofoil as well as surfaces of multicurvature. It appears that negotiations were carried on with a British aircraft constructor for its utilization and Turnbull went to England just prior to 1914 to conclude the matter. However, the deal fell through and Turnbull allowed the patent to lapse. One wonders if this patent was not one of the great basic patents of the art comparable with that which led to the Wright patent litigation of 1909-10.

Turnbull also examined the significance of his results with respect to natural flight. He disagreed with Lilienthal's assumption that the bird's wing is slightly concave in profile and showed that the average is concave-convex. He demonstrated that on the downstroke a bird's wing assumes a concave-convex profile and on the upstroke, a convex profile both of which his experiments had shown had automatic longitudinal stability, the convex on the upstroke having low lift (negative) and low drag and the concave-convex, on the downstroke, having high lift and low drag.

For soaring bird flight Turnbull demonstrated that the characteristics of a concave-convex wing of reduced curvature provided a rational explanation for the soaring flight of birds in ascending air currents. He reasoned that the automatic stability of birds derived primarily from the wing profile and that the tail is a valuable auxiliary but not essential (since it is almost lacking in some species).

The interest displayed by Turnbull in bird flight was not unusual at that time, since the birds were being looked to by man for guidance in achieving human flight. However, with Turnbull it was to continue, and he was, near the time of his death devoting time to the study of bird flight.

In this series of experiments Turnbull also measured the influence of an underplane on the lift of aerofoils, i.e. what is now termed "ground effect" and was probably the first to do so. He measured the effect of a surface one-half inch below the trailing edge of the aerofoils and concluded that the increase in lift caused, was greater for plane and double curvature aerofoils than for those of single curvature. Under certain conditions the lift might be nearly doubled but the effect virtually disappeared for a height above the surface of one-third chord.

He considered that ground effect on lift might be important in landing and take-off when the speed is low and a maximum lift is desired.

He realized that wing height would be influenced by considerations such as propeller tip clearance and that the accompanying increase in drift and aft travel of the c.p. could not be ignored but might be overcome.

Turnbull had opened his paper by emphasizing that the problem of aerial navigation would not be really solved until the mechanical engineer had at his command full data concerning lift, drag, c.p., and stability of aerofoils; thrust and efficiency of propellers (note this) and strength and suitability of materials. He pointed out the crying need in aeronautics of research work, deplored the fact that so many scientific workers were content to pass and repass over the footsteps of others and so few were willing to take up the laws of aerodynamics and reduce them to an exact science.

In summing up his paper, the engineer in Turnbull again came to the fore, as he pointed out that the results given, while clearly indicating the type of aerofoil to be adopted and the type to be avoided in designing an aeroplane, could give little help in proportioning the parts, an essential feature in the general design of a practical aeroplane.

This paper constituted a most valuable contribution to the science of aeronautics and Turnbull's results were widely quoted in the literature[20].

During 1911 he experimented with staggered planes or what are now called cascades. One such cascade comprised some eleven aerofoils of about 6-inch chord and varying span, 3-6 feet with a gap:chord ratio of about one and negative stagger of one chord.

AEROPLANE EFFICIENCY

Turnbull developed his views on the engineering design of aeroplanes and raised, perhaps for the first

[d]See appended list of patents.

time, the question of efficiency in a paper, based on that in the Physical Review, *The Efficiency of Aeroplanes, Propellers and Motors etc.*, read before the Aeronautical Society of Great Britain, 11 May 1908[21].

He pointed out that most designers of the time ignored the importance of the efficiency of the parts – the wings were large enough to provide the required lift but the drift was enormous, the propellers were too small and the motor so poorly cooled and adjusted as to be incapable of delivering its rated power. Any one of these faults might cause failure, but combined, as was usual, they rendered a machine hopeless.

At the time he had just returned from France and commented that even the most successful of the aircraft of that day were, at best, crude, the most successful machine using 38 hp to carry a man at 30 mph.

He continued that, as in most engineering design, the design of the aeroplane was a series of compromises at every point, the wing shape to meet mechanical considerations, the propeller to conform with the rest of the design and the engines to save weight. He pointed out that inefficient wings meant larger propellers, inefficient propellers meant larger engines, larger engines meant larger aeroplanes and so on "at compound interest".

Turnbull first considered wing efficiency and presented in his paper the efficiencies, i.e. lift/drift, of the five aerofoils previously tested, with graphs of lift/drift plotted on incidence. The results indicated that the concave-convex profile had the highest maximum L/D, 5.65 at 8¾°, as compared with a maximum of 4.6 at 5° for the commonly used concave profile. Further this high efficiency could be increased by making the forward concave portion ⅔ of the chord and the rear convex ⅓ of the chord instead of ½ chord for each. He concluded that this high efficiency, coupled with automatic longitudinal stability pointed to the concave-convex profile as being the best available.

Turning to the propeller Turnbull remarked that the subject was most difficult to cope with because of the meagre data available. He commented that a very complete research on the subject was sorely needed. He himself was shortly to undertake such a research. Until adequate and reliable data were available makeshift methods had to suffice. He obtained data for a number (24) of good and bad air propellers and compared them by plotting tip speed against estimated horsepower in one graph, and against thrust per bhp. in a second graph. While the scatter of the points was large, a mean curve showed 40 hp. at 31,000 fpm., where five propellers of the day gave practically the same performance. He concluded that this result was therefore representative of a propeller with two narrow concave blades "driven at much too high a speed for good efficiency".

Turnbull encountered difficulty in plotting the second curve because of lack of accurate thrust data. Of the eight points plotted five were for "modern" high speed screws five to seven feet in diameter. The average graph plotted showed a decrease in efficiency with increase in speed, thus the aeroplane of that time had a propeller giving a thrust of about 7 lb./hp. at 30,000 fpm. whereas thrusts of 40 lb./hp. seemed possible in the most efficient screws, i.e. large diameter, slow speed. Turnbull commented that the compromise of using a small high speed screw to suit the rest of the design had cost the aeroplane an enormous toll namely an engine six times heavier than necessary. The successful machines had succeeded in making short flights only by virtue of marvellously light powerful motors.

Turnbull stated that he could not say what the ideal means of propulsion was for an aeroplane but that he was constantly shaping his experiments to overcome this difficulty which had faced him from the beginning of his work.

Later, in an article on *The Efficiency of Aerial Propellers*[22] he wrote "Sooner or later we will be forced to study this subject of efficiency if we are to arrive at a practical solution of aerial navigation and the present indications are that the airscrew is not the ideal means of propulsion at least for aeroplane machines of the present type".

Finally he considered the efficiency of the motor, i.e. the specific weight, in other words the weight of motor and accessories per bhp. He stated, with feeling, that the efficiency was "impossible to determine as it is a very variable quantity much to the discomfiture of the experimenter".

Extravagant claims were made by the engine manufacturers of that day, of from 4 down to 1.6 lb./hp. which were not fulfilled. The cooling of practically all motors of the time was such that power fell off alarmingly after about ten minutes operation and Turnbull pointed out that an engine weighing 4 lb./hp. whose power drops fifty per cent in ten minutes is really an 8 lb./hp. engine.

Nevertheless, he considered the gasoline engine to possess wonderful possibilities and that present difficulties would ultimately be overcome.

He concluded that a wing of fair efficiency was available and the motor had possibilities, but the bête noir of the problem lay in the unsuitability of the airscrew as a means of propulsion because correct mechanical design could not be achieved without impossible distortion and absurd mechanical construction.

For this paper the Aeronautical Society on 28 January 1909 awarded Turnbull the Bronze Medal of the Society as the best paper published in the Journal during 1908. This Medal is now in the New Brunswick Museum in St. John.

Implementing a promise made the previous October, Turnbull wrote[23] to Alexander Graham Bell on 30 June 1908 from the westbound Empress of India giving a few observations on French aeronautical engines he had seen during a trip in an unsuccessful search for a reliable aeromotor. It was during this trip that he read the foregoing paper in London.

He wrote that in Farman's opinion there was no really satisfactory engine available in France. All engines, and particularly air cooled, gave their rated power for about ten minutes only. Farman's Antoinette engine was cooled by the evaporation of the small quantity of water initially in the jackets and runs were hence short. Turnbull recommended to Bell the Duteil and Chalmers twin opposed engine as the best available. The patented cooling system used the fuel in the jackets. He advised Dr. Bell to order any engine on a strict contract guar-

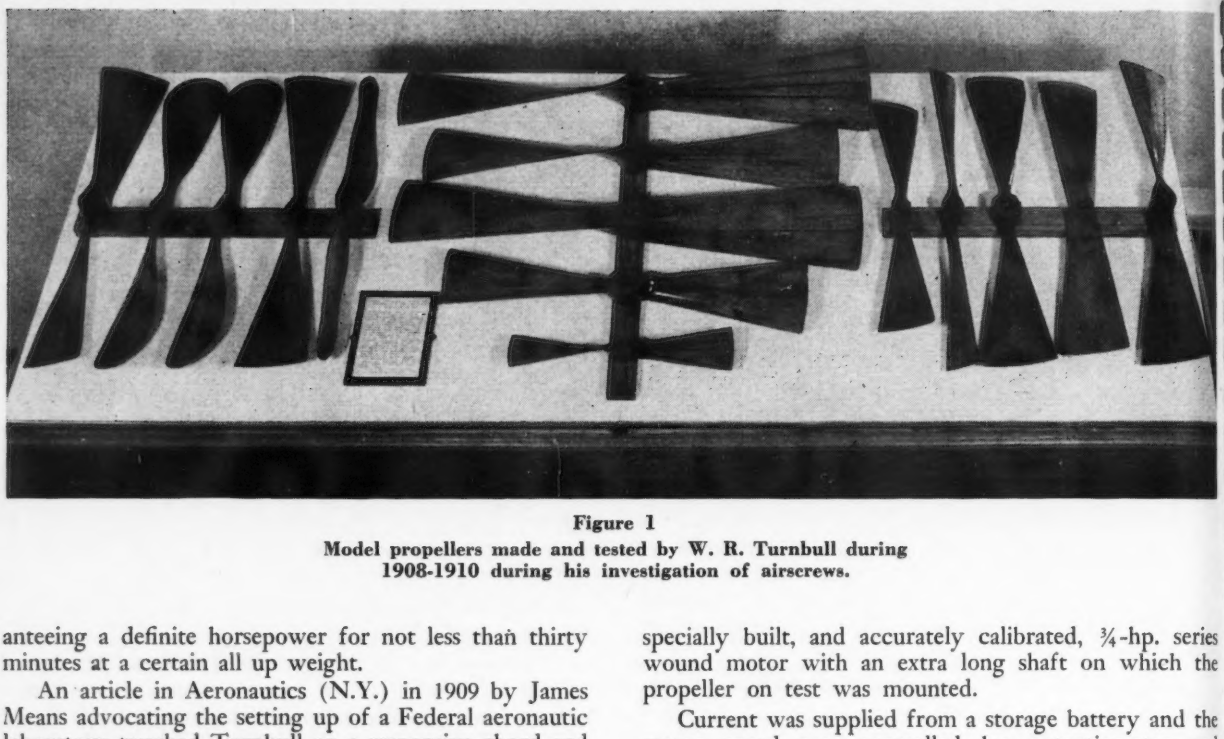


Figure 1
Model propellers made and tested by W. R. Turnbull during 1908-1910 during his investigation of airscrews.

anteeing a definite horsepower for not less than thirty minutes at a certain all up weight.

An article in Aeronautics (N.Y.) in 1909 by James Means advocating the setting up of a Federal aeronautic laboratory touched Turnbull on a responsive chord and led him to comment[24]. He pointed out that little had yet been achieved in solving the problem of aerial navigation. The contemporary aeroplane had virtually the same limitations as the dirigible balloon. The aeroplane was a direct refutation of Langley's law that the higher the speed the less the power required to drive it. His own indirect experiments, while not in any sense conclusive, all pointed to the law being in error and this was only one of several important points whose clarification was necessary to put the subject on a scientific basis.

Turnbull considered the aeroplane of that day a soaring machine made possible only by the very light motors available, rather than a true flying machine. The soaring machine was not practical in a gusty wind and hence not a solution. The contemporary aeroplane was not conceived on correct principles and until correct principles were discoverd by painstaking research work development would be at a standstill. He concluded, "We cannot build on sand, let us have the research work for a foundation".

AIRSCREWS

Although earlier, as has been seen, Turnbull had doubted that the screw propeller was the ideal means of propulsion for the aeroplane of the time, he apparently became resigned to its use and, since the propeller was poorly understood and reliable data pertaining to it were lacking, he proceeded to remedy the situation. Between 1908-10 he undertook an experimental study to determine data on which the design of airscrews could be based.

The first experiments were made on fixed airscrews, i.e. without axial motion[25]. For the tests Turnbull constructed a dynamometer consisting of a small platform, suspended on four long wires, on which he mounted a specially built, and accurately calibrated, ¾-hp. series wound motor with an extra long shaft on which the propeller on test was mounted.

Current was supplied from a storage battery and the motor speed was controlled by potentiometer and measured by speed counter.

The thrust of the propeller was measured by weights on a scale pan suspended on a wire passing over a frictionless pulley to the platform.

The two-bladed model screws were made of laminated white pine in several systematic series[e] having diameters ranging from 1.5 to 3.5 feet, pitches from 1.0 to 5.0 feet, cambers of driving face from zero to .034 and with square or rounded blade tips.

The results of the tests indicated that for similar propellers the thrust varied as D^4 and power as D^5. Plotted graphs of thrust coefficient U and power coefficient Q enabled the thrust and horsepower to be calculated from the formulae:

$$T = UN^2D^4$$
$$P = QN^2D^5$$

D being diameter in feet and N speed in rpm.

In those days, the useful effect of airscrews L was measured in lb./bhp. Turnbull considered that this should be multiplied by the "pitch speed" and he gave the useful effect determined in his experiments in terms of $L.P.N$. He deduced that the useful effect was equal to $U/Q \cdot P/D$ and hence independent of diameter and speed but greatly dependent on the pitch coefficient, i.e. pitch:diameter ratio, and slightly on blade width. It followed that the thrust per bhp. varied inversely as pitch speed, PR, making the useful effect constant for a given pitch coefficient and propeller type. His results gave a maximum useful effect at a P/D of 1.2 and this explained why the French fine pitch propellers were inefficient and the Wright propellers, with a P/D equal to 1.2, were so efficient.

[e]All of the models except No. IX were presented to, and are now displayed in the Aeronautical Museum of the National Research Council.

Using the same flat bladed models and a carriage and track, Turnbull then experimented with propellers in forward motion[26].

The first recorded use of a carriage and track was by an Italian mathematician, Avanzini[27], in 1804. In 1909 at the Frankfort Exhibition a carriage and track were used for propeller experiments[28]. These, with Turnbull's, were the first tests in which input and output power and efficiency were measured for propellers in axial motion.

Turnbull's track was of 30 inch gauge and some 343 feet long, of iron, bonded at the joints over most of the length, and shielded on one side by a grove of trees. The first 68 feet of the track was inclined to accelerate the carriage and the last portion had wooden rails which cut off the power and applied brakes. The remainder was straight and level, measurements being recorded over the middle 100 feet where the speed of the carriage was constant. Current was carried to the propeller motor through the rails and wheels.

The dynamometer used in these experiments comprised the same propeller motor mounted on a truck rolling on short rails on the carriage. Thrust of the propeller was transferred through a calibrated spring from the truck to the carriage, the extension of the spring being recorded, together with motor rpm. on a disk of paper rotating in proportion to the movement of the car. The speed of the carriage was recorded on a chronograph[f] by means of brass contacts at 50-foot intervals along the track, and a seconds pendulum. The maximum carriage speed was 25 fps.

The general results of the experiments showed that there was a reduction of thrust when axial motion began and that, contrary to a belief current at the time, the efficiency was not constant but varied with axial speed and reached a maximum, depending on diameter, pitch coefficient[g] and so on, at a certain speed.

Thus, as the "apparent"[h] slip decreased from 100 per cent (no axial motion) the efficiency increased to a maximum at an apparent slip of about 40 per cent, decreasing from there to zero, of course, at zero slip. The slip for maximum efficiency decreased with increase in diameter, rapidly at first, then flattening out to a slip of about 30 per cent at diameters over 9 to 10 feet.

Turnbull's results when plotted indicated that the range covered by his experiments was inadequate in that the graphs, for example, of efficiency were still, in most cases rising. However, he was able to extend the curves by "fair approximations". For a screw of 2.5-foot diameter the maximum efficiency thus indicated was about 45 per cent for a pitch coefficient of 1.6. By extrapolation these results indicated an efficiency of 80 per cent for a 10-foot diameter at a pitch coefficient of 1.4.

While the scope of the experiments was unfortunately limited, the results nevertheless indicated some of the mistakes made in many current designs and provided data on which efficient airscrews could be designed.

[f]This chronograph was recently presented to the Aeronautical Museum of the National Research Council by Mr. D. O. Turnbull.

[g]Pitch coefficient was the average geometric pitch divided by diameter. The modern term is advance diameter ratio $J = V/ND$.

[h]Apparent slip (per cent) $= \dfrac{PN - V}{PN}$

Thus the experiments showed that efficiency increased with pitch coefficient up to a maximum at a P/D of about 1.25 to 1.50 and that efficiency increased with diameter rapidly at first and then more slowly. This indicated the loss in efficiency in coupling a low pitch airscrew to a high speed motor.

Turnbull suggested that the proper way to achieve high efficiency, was to select the largest diameter that the configuration of the machine would permit, and a pitch coefficient of about 1.35. From the designed speed of the aeroplane calculate the speed of the propeller allowing a proper percentage slip obtained from the graphs in his paper, and finally gear down the engine speed to that of the propeller. This procedure would give the maximum efficiency for the conditions, any loss due to the reduction gearing being more than offset by the gain in propeller efficiency.

He again emphasized the importance of the highest efficiency in the aeroplane and the dependence, to a certain extent, of the efficiency of every part on that of every other part. He believed that undue importance had been attached to blade profile and form and too little to diameter and pitch coefficient. There was no question, in his opinion, of more importance to the scientific and engineering phase of aerial navigation than that of propeller efficiency.

The Wright brothers had appreciated this point and, by adopting proper diameter, pitch ratio and speed, by gearing down the motor speed, had obtained a propeller efficiency of 65 to 70 per cent as compared with a "supposed" efficiency of about 50 per cent in other current propellers. His results and theory indicated a possible maximum efficiency of the order of 80 per cent.

LAWS OF AERODYNAMICS

During the period 1906-12 Turnbull experimented with a great variety of devices "calculated" to obtain dynamic support from the air, including aerofoils, airscrews, wing flapping machines (ornithopters), rotary wings (helicopters), feathering paddle wheels and various devices for producing mechanically a partial vacuum above a supporting surface. Careful measurements of the lift and power required at different speeds were made in each case and from the results he concluded that regardless of the device, the following law was valid. "*The efficiency*[i] *of any device designed to obtain dynamic support from the atmosphere, increases as the quantity of air acted upon increases and as the velocity of the air acted upon decreases.*" In other words, in the case of the aeroplane, the greater the wing area (and aspect ratio) and the lower the downward speed of the deflected air, the higher the efficiency.

While this law had been recognized in a general way with respect to the aeroplane and airscrew, Turnbull was the first to point out and emphasize its applicability to all devices deriving dynamic support from the air. The law had certainly been unnoticed by most designers and ignored by scientific writers, possibly because of difficulty in reconciling it with Langley's so-called law. The latter law was the subject of much misunderstanding and controversy in the early days.

In *Experiments in Aerodynamics* of 1891 Langley stated that his experiments showed that for a plane of

[i]Defined as weight lifted and sustained per power unit.

fixed size and weight moving at an angle and speed such that it is sustained in horizontal flight, then the higher the speed the less the power required. The statement came to be known as "Langley's Law". Langley regarded the statement as theoretical and not to be expected to apply fully in practice. He suggested that the maximum efficiency would be reached at some remote speed not yet attained in experiment. However, Turnbull showed in a paper[29] in 1912 that Langley's conclusion was invalidated by the assumptions and data used and that had he used his own data Langley would have found that the speed for maximum efficiency was not remote but moderate and practical and might be as low as 20 mph. Turnbull further showed that Langley's conclusion (law) applied only up to the speed for maximum efficiency.

Using Langley's own data and those of Eiffel, Turnbull indicated the correct conclusion and derived a general law of the aeroplane as "*The weight per unit of power supported by an inclined aeroplane in horizontal flight increases as the speed increases up to a certain maximum value, after which it decreases as the speed increases. The said maximum is the higher (and occurs at the lower speed) the greater the supporting area in proportion to the weight sustained.*"

This law was probably more or less understood by aviators and designers of the time but Turnbull was the first to express it in concrete form. The law was a special application to the aeroplane of his earlier law. Langley's law (or paradox) was seen to be but the first phase of Turnbull's more general law.

These laws were of broad significance and Turnbull emphasized that a clear understanding of such fundamentals (laws) was important and would save much aimless and wasteful experimenting, as, for example, attempts to produce mechanically a vacuum above a plane since they depend on removing a small quantity of air at high velocity, which, Turnbull's first law showed was inefficient.

FREDERICK SAGE AND CO. LTD., PETERBOROUGH, ENGLAND

Early in the First World War, Turnbull went to England and volunteered his services without remuneration to several well-known aircraft manufacturing companies without success. More or less by accident he met Mr. E. C. Gordon England, formerly with the Bristol Company and one of the earliest British experimental pilots and constructors. England was then General Manager of the Aviation Department of Frederick Sage and Company Limited, an old established firm of shop fitters, who, in the spring of 1915 at the request of the Admiralty had embarked on the manufacture of aircraft and aircraft propellers and employed some four thousand personnel in three factories. The firm built numbers of the Short Seaplane, Admiralty type 184, and Avro 504K and also designed and built the Sage 1, Sage 2 Scout, Sage 3, Sage 4a, b and c but gave up aircraft production in 1919 and returned to its original line. The firm is still in existence.

At the time of the meeting, England was engaged in building up a team to design military aircraft. He had gathered around him a number of the earliest hands in aviation. England was impressed with Turnbull and was confident that opportunities would very soon appear for making full use of his long experience and knowledge. England assured Turnbull that he would welcome him as a member of his team and not without remuneration. Turnbull refused to take a leading part in the team England was organizing, pointing out the importance of picking young men for leadership so that they would have a clear appreciation of the opportunities before them. Turnbull wished to act more as adviser, counsellor and guide to the younger men, and, in any event he intended to return to Canada as soon as the war was over which would leave a gap in the continuity.

England engaged Turnbull originally to take charge of the aircraft inspection department but gave him a free hand to undertake research and development on his own, and eventually put him in charge of the development section where his genius had scope in developing original ideas without interference or distraction. It will be seen that he was a prolific inventor.

Turnbull did much of the propeller design for Sages and was highly successful. His propellers were very efficient and the success of a Sage seaplane of 1916 was attributed largely to its propeller, designed by Turnbull. The seaplane two passenger altitude record of 13,000 feet was attained by a Short 184 seaplane fitted with a Turnbull propeller on 9 June 1917 over the Isle of Sheppey, with Turnbull on board as an observer.

(To be continued in the next issue)

ALUMINUM ALLOYS FOR ELEVATED TEMPERATURE SERVICE†

by E. H. Dix, Jr.*

Aluminum Company of America

ALUMINUM alloys have been, since the spruce and wire days, the principal materials for the structural components of aircraft. With the advent of jet propulsion and high speed aircraft, the performance of materials at elevated temperatures has received the earnest attention of those concerned with aircraft progress. It was early recognized that aluminum alloys faced certain limitations in this respect and the search for alloys with improved elevated temperature properties has been diligent, but progress has been difficult.

No one expects the metallurgist to be able to raise the melting point of aluminum, and since the structural aluminum alloys all achieve their high strength by heat treatment, their strength is impaired by reheating beyond certain temperatures. Some recent developments, to be discussed later, have made available products of higher melting point than the conventionally prepared alloys and which have exceptionally stable properties for a long time at elevated temperatures. The problem is further complicated by variations in the time-temperature relations in different applications. The time varies from a matter of seconds for some missiles to 100 hours, 1,000 hours or longer for piloted aircraft.

There has been a tendency to apply the oversimplified criterion of strength-weight ratio in comparing aluminum alloys with other metals, such as titanium and stainless steel, for elevated temperature service. This has led to the fairly general opinion that the days of aluminum structures for high speed aircraft are numbered. The aluminum industry, always reluctant to lose an established use, is fighting hard to retain this business and the situation is more favorable than has sometimes been indicated.

Research has developed new alloys and powder metallurgy products which represent distinct improvements in elevated temperature properties. These improved products have been discussed informally for several years without creating as much interest in the aircraft industry as they deserve. Perhaps the timing has been bad, or it may be a case of too little too late. It is possible that even the present aluminum alloys perform so much better at mildly elevated temperatures than some nonmetallic materials essential for high speed aircraft, for instance those required for transparent enclosures and radomes, that the aluminum alloy elevated temperature problem is not yet critical.

As evidence of current interest, in March 1955 two informative articles appeared, one from England and one from this country. Major P. L. Teed, in his article[1] *Metallurgy and Stratospheric Flight*, stated, "Dealing with the world as it is and not looking too far forward, a speed at stratospheric heights of 1,400 miles an hour appears to be attainable within the next ten years!" He further indicated that at this speed at 50,000 feet, the surface of an aircraft with turbulent flow would reach a temperature of about 212°F.

In the other article[2] by N. E. Promisel, a curve is presented indicating a somewhat higher skin temperature, slightly under 300°F., produced by the effect of aerodynamic heating at a speed of 1,400 miles per hour at an altitude of 50,000 feet. Mr. Promisel stated, however, that recently a plane had flown at a speed of over 1,600 miles per hour, which, if maintained for a long enough time, would have raised the skin temperature to about 400°F. It is evident, therefore, that at the present time we are facing skin temperatures of from 200° to 400°F. in supersonic flight from aerodynamic heating alone. Undoubtedly, there are military planes now being designed which are expected to exceed the speeds mentioned, and therefore, skin temperatures exceeding 400°F. may result. In addition to heat generated by this cause, locations always exist where there is a chance of heating from proximity to power plants and from intentional heating for the purpose of de-icing and cabin heating; thus, some structural airframe members may reach a temperature of 600°F. in piloted craft and much higher but for a shorter time in missiles.

In discussing structural uses at elevated temperatures, it is well to remember that even at room temperature aluminum alloys cannot compete on a strictly tensile strength-weight basis with the best titanium alloys or high strength steels. But aluminum alloys probably make up 80 percent of the structure of current planes. One reason is that they possess an advantage in shear or compression where buckling is the controlling factor in design. In such applications, the low density of aluminum alloys can be exploited effectively to increase the stiffness of the parts, thus offsetting the strength advantage of the heavier metals. At what temperature will this predomin-

†Paper read by F. M. HOWELL at the I.A.S./C.A.I. International Meeting in Ottawa on the 4th November 1955.
*Assistant Director of Research

ance of aluminum alloys be reduced significantly? No one seems to be able to give a categorical answer to this and similar questions. However, Mr. Promisel states, "In compression plate applications where buckling is critical and, under some conditions in shear . . ., steel appears to be of dubious merit at all temperatures and aluminum has the advantage even at moderately high temperatures, possibly up to 500° or 600°F."

It is, therefore, timely to present to the aircraft industry, in a formal manner, the most up-to-date information on elevated temperature properties of current and newly developed aluminum products. The aluminum and aircraft industries have a joint responsibility to determine whether the new products have sufficient promise to justify the cost of time-consuming programs required by both industries to successfully introduce a new product.

WROUGHT ALUMINUM ALLOYS FOR AIRFRAMES

The wrought alloys currently used in airframes may be divided into two types. The aluminum-zinc-magnesium-copper alloys (7075, X7178, X7079) in the -T6 temper have the highest strength at room temperature, but as is well known, the strength falls off rapidly at temperatures exceeding 200° to 250°F., especially after long times at temperature. Alloys 7075 and X7178 are used in the form of sheet, plate and extrusions, and 7075 and X7079 as forgings. Alloy 7075-T6[a] will be used as representative of this group. The aluminum-copper-magnesium alloys (2014 and 2024) represent the second type and are the presently preferred alloys if elevated temperatures are anticipated. Alloy 2014 is currently used in the artificially aged temper (-T6); alloy 2024 is generally used in the naturally aged temper (-T4). Both alloys are available as extrusions, sheet and plate; however, for aircraft 2014 alloy sheet is generally in alclad form. Alloy 2014 is also extensively used for forgings. For elevated temperature applications, the -T6 temper is preferred not only because of the higher initial strength but also because the properties are more stable; otherwise aging occurs at such temperatures. Also, if the initial temper is -T4, an intermediate microstructural condition occurs during aging which results in a lowered resistance to corrosion. Further aging to the full -T6 temper restores the resistance to corrosion.

Forging alloy 2618-T61

For forgings in power plant applications, alloy 2618-T61[b] has received favorable consideration from the time it was introduced in the United States from England in the specifications for the American-made Nene engine. Alloy 2014-T6 has been used extensively and satisfactorily for forgings in similar applications for many years.

New experimental alloys

A new alloy, X2219-T6, is an independent development in the United States although it contains copper and manganese contents similar to the British alloy RR57. The alloy contains, in addition to the copper (6.0%) and manganese (0.3%), small quantities of vanadium and zirconium and is covered by a recently issued U.S. patent.[c] It has outstanding properties at temperatures above 500°F. At the present time this alloy is experimental, as indicated by the "X" status, for extrusions and forgings. Should sufficient demand develop, it could also be made available for sheet and plate.

Alloy M237,[d] as its designation indicates, is still in the laboratory stage and it has not yet been determined whether it can be produced commercially. However, it is being considered for sheet, plate and extrusions. Its properties are such as to make it of considerable interest in the temperature range 300°-400°F. which, for the next few years, seems to be the most important range.

Aluminum Powder Metallurgy products

Following the discovery in Switzerland of the unique characteristics of wrought products made from fine aluminum flake powder containing appreciable amounts of aluminum oxide, there has been extensive development both in the United States and Europe of products of this type. At the present time, Alcoa is experimentally producing compacts up to 21" in diameter and weighing up to 800 pounds. These compacts are fabricated by extrusion in the same manner as ingots produced by the conventional casting process. The extrusions may, if desired, be further forged or rolled into sheet.

The properties of these products vary with the particle size and oxide content. The smaller the particle size and the higher the oxide content, the greater the strength and the lower the workability and ductility of the product.

Alcoa has produced experimental quantities of sheet, foil, extrusions and forgings which are being tested by a number of companies. Several applications involving extrusions and forgings have reached the stage of commercial use.

It should be emphasized, however, that since the manufacture of compacts is not yet carried out under production conditions, large quantities of these products can be made available only after production facilities for compacts are established. So far, the demand for the products has not justified taking this step. The product, which is being investigated most extensively, is identified as M257. It is readily forgeable and sheet of this material has a formability about equivalent to that of 7075-T6. Another product of higher strength has been designated M276. It is more difficult to work than M257 and less experience has been gained with it but, a product with its properties can be made available. Because of the high oxide content, brazing or fusion welding procedures have not yet been successfully worked out for the APM (Aluminum Powder Metallurgy) products.

Above about 600°F., these APM products have strengths superior to any conventionally produced aluminum alloys, and since aluminum oxide is insoluble in solid aluminum, the stability of properties is remarkable. Furthermore, since the powder is unalloyed, it has a melting point as high as that of pure aluminum. Even when heated above the melting point of aluminum, the APM products maintain their shape to a considerable extent; that is, they do not become liquid and flow as conventional alloys do.

[a]U.S. Patent 2,240,940.
[b]U.S. Patent 2,522,575.
[c]U.S. Patent 2,706,680.
[d]Patent pending.

Presentation of Data: Wrought Alloys

The data on the wrought alloys just discussed, available at Aluminum Research Laboratories, are given in the following tables. Table 1 lists the nominal chemical compositions of the wrought alloys to be discussed with the exception of that of M237 which is omitted because the alloy has no commercial standing. This laboratory composition is a modification of that of alloy X2219. Its elevated temperature properties are sufficiently different from those of X2219 to justify presenting the properties of both in order to determine which is most acceptable to the aircraft industry.

Table 2 gives the tensile properties at temperatures from room temperature to 700°F. after periods of time at temperature of from ½ to 10,000 hours. The data on the standard airframe alloys (7075-T6, 2024-T4 and 2014-T6) are the weighted averages of tests of a number of lots of products. In the case of the first two alloys, the data include tests on commercially produced rolled-and-drawn rod, and for the 2014-T6 on both rolled-and-drawn rod and forgings. The properties for 2618-T61, X2219-T6, and M237 are more limited and are confined to tests on forgings only. The APM products were tested in the form of extrusions.

TABLE 1
Nominal Compositions of Wrought Aluminum Alloys

	7075	2024	2014	2618	X2219
Cu	1.6	4.5	4.5	2.2	6.0
Fe	–	–	–	1.1	–
Si	–	–	0.9	–	–
Mn	–	0.65	0.8	–	0.3
Mg	2.5	1.5	0.5	1.6	–
Zn	5.7	–	–	–	–
Cr	0.25	–	–	–	–
Ni	–	–	–	1.05	–
Ti	–	–	–	0.07	–
V	–	–	–	–	0.10
Zr	–	–	–	–	0.15

Table 3 gives the stress required to produce stress rupture in 1 to 1,000 hours and creep of 0.1% to 1% in the same periods of time. The data for 7075-T6 and 2024-T4 were obtained from sheet and rolled-and-drawn rod, and for 2014-T6, from forgings and rolled-and-drawn rod. Data for 2618-T61, X2219-T6 and M237 were obtained from forgings, and APM products from extrusions. Creep, as reported in this table, is the flow or plastic deformation that occurs with time under a constant load, after the initial deformation resulting from the application of load. Compressive creep tests made at Cornell Aeronautical Laboratory indicate that compressive creep follows approximately the same pattern as tensile creep.

In Table 4 the fatigue properties are presented at temperatures up to 600°F. For 7075-T6, these properties were obtained on rolled-and-drawn rod; for 2024-T4 on extruded bar; for 2014-T6 on forgings, rolled-and-drawn rod and extrusions; for 2618-T61, X2219-T6 and M237 on forgings; and for APM products on extrusions.

Figures 1 and 2 give the room temperature tensile properties of the various alloys after heating for 100 and 1,000 hours at various temperatures. These data were obtained from tests of sheet, plate, and rolled-and-drawn rod of 7075-T6; plate of 2024-T4; sheet, plate, forgings and rolled-and-drawn rod of 2014-T6; forgings of 2618-T61; sheet of X2219-T6 and M237; and extrusions of the APM products.

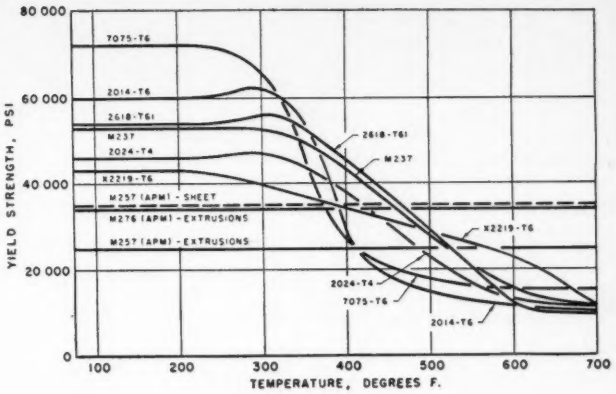


Figure 1
Yield strength of wrought alloys at room temperature after 100 hours at temperature

The tensile yield strength data from Table 2 have been plotted in Figures 3 and 4, for 100 hours and 1,000 hours respectively. The values for compressive yield strength do not differ greatly from the tensile yield strength at room temperature and come even closer together as the testing temperature increases, as indicated by tests made at Armour Research Foundation. In Figures 5 and 6, the tensile yield strength has been plotted against time at temperature for temperatures of 300°F. and 600°F. respectively. These latter curves are of particular interest in indicating the degree of stability of the tensile properties during prolonged heating.

Discussion of Data: Wrought Alloys

A comparison of the elevated temperature characteristics of the various alloys under discussion can best be started with a consideration of the well-known airframe alloys, 2024 and 2014. The tensile yield strengths of 2024 are given for simplicity in only the -T4 temper. The

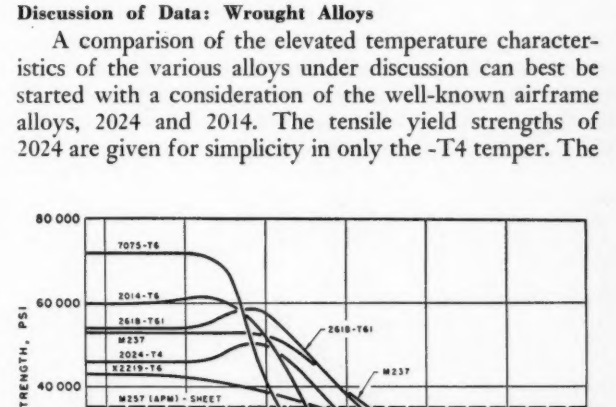


Figure 2
Yield strength of wrought alloys at room temperature after 1,000 hours at temperature

TABLE 2

Tensile Properties of Some Aluminum Alloys at Elevated Temperatures

	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %
Alloy	7075-T6			2024-T4			2014-T6			2618-T61		
Room Temperature	82 000	72 000	11	68 000	46 000	22	70 000	60 000	13	64 000	54 000	10
212°F — 1/2 Hr.	72 000	64 000	15	61 000	43 000	23	66 000	56 000	13	64 000	54 000	10
100 Hr.	72 000	64 000	15	63 000	45 000	23	67 000	57 000	13	64 000	54 000	10
1000 Hr.	72 000	65 000	15	62 000	45 000	23	68 000	60 000	13	64 000	55 000	9
10000 Hr.	65 000	60 000	15	62 000	44 000	20	69 000	63 000	14	65 000	55 000	9
300°F — 1/2 Hr.	57 000	51 000	20	56 000	40 000	28	59 000	51 000	13	57 000	51 000	14
100 Hr.	48 000	45 000	20	58 000	46 000	19	59 000	54 000	13	58 000	52 000	13
1000 Hr.	32 000	29 000	25	52 000	44 000	20	56 000	51 000	14	54 000	48 000	13
10000 Hr.	25 000	21 000	30	43 000	36 000	20	47 000	40 000	15	50 000	45 000	13
400°F — 1/2 Hr.	38 000	34 000	20	51 000	36 000	25	46 000	43 000	13	46 000	43 000	14
100 Hr.	17 000	15 000	40	37 000	31 000	22	33 000	29 000	20	39 000	34 000	17
1000 Hr.	15 000	13 000	50	31 000	27 000	24	23 000	18 000	30	34 000	31 000	20
10000 Hr.	14 000	12 000	60	26 000	21 000	25	18 000	12 000	35	33 000	30 000	25
500°F — 1/2 Hr.	36 000	14 000	35	29 000	23 000	22	28 000	25 000	18	29 000	26 000	25
100 Hr.	12 000	9 500	50	20 000	15 000	38	15 000	12 000	30	21 000	17 000	35
1000 Hr.	11 000	9 000	60	16 000	12 000	42	12 000	10 000	40	19 000	13 000	45
10000 Hr.	11 000	9 000	65	14 000	9 500	45	11 000	8 500	45	–	–	–
600°F — 1/2 Hr.	9 500	7 000	55	15 000	12 000	35	10 000	9 000	30	21 000	18 000	30
100 Hr.	8 500	6 500	80	10 000	7 500	65	8 000	6 500	50	11 000	7 500	65
1000 Hr.	8 500	6 500	80	8 000	5 500	70	7 000	5 000	60	9 000	6 000	75
10000 Hr.	8 500	6 500	80	7 500	5 000	75	6 500	5 000	65	7 500	5 500	80
700°F — 1/2 Hr.	6 500	5 000	60	7 500	6 000	55	6 000	5 000	50	8 500	6 500	50
100 Hr.	6 000	4 500	65	5 500	4 000	95	5 000	4 000	60	5 500	4 000	–
1000 Hr.	6 000	4 500	65	5 000	3 500	100	4 500	3 500	65	5 000	3 500	–
10000 Hr.	6 000	4 500	65	5 000	3 500	100	4 500	3 500	70	–	–	–
Alloy	X2219-T6			M237			M257 (APM)			M276 (APM)		
Room Temperature	62 000	43 000	16	69 000	53 000	12	38 000	25 000	17	51 000	34 000	7
212°F — 1/2 Hr.	–	–	–	–	–	–	–	–	–	–	–	–
100 Hr.	–	–	–	–	–	–	–	–	–	–	–	–
1000 Hr.	–	–	–	–	–	–	–	–	–	–	–	–
10000 Hr.	–	–	–	–	–	–	–	–	–	–	–	–
300°F — 1/2 Hr.	52 000	41 000	22	60 000	50 000	16	–	–	–	–	–	–
100 Hr.	52 000	42 000	22	60 000	49 000	16	–	–	–	–	–	–
1000 Hr.	50 000	37 000	19	60 000	49 000	17	–	–	–	–	–	–
10000 Hr.	46 000	32 000	19	58 000	47 000	16	–	–	–	–	–	–
400°F — 1/2 Hr.	39 000	34 000	24	51 000	44 000	19	21 000	18 000	16	32 000	27 000	6
100 Hr.	38 000	28 000	21	46 000	38 000	20	21 000	18 000	16	32 000	27 000	6
1000 Hr.	38 000	27 000	21	37 000	31 000	24	21 000	18 000	16	31 000	26 000	6
10000 Hr.	–	–	–	–	–	–	–	–	–	–	–	–
500°F — 1/2 Hr.	29 000	24 000	23	34 000	31 000	25	19 000	16 000	17	26 000	23 000	7
100 Hr.	29 000	22 000	24	26 000	23 000	28	19 000	16 000	17	26 000	23 000	7
1000 Hr.	29 000	22 000	24	26 000	21 000	27	19 000	16 000	17	26 000	23 000	7
10000 Hr.	–	–	–	–	–	–	–	–	–	–	–	–
600°F — 1/2 Hr.	21 000	17 000	25	18 000	16 000	25	16 000	14 000	15	22 000	20 000	6
100 Hr.	20 000	15 000	25	15 000	13 000	30	16 000	14 000	12	22 000	20 000	6
1000 Hr.	18 000	14 000	27	15 000	13 000	29	16 000	14 000	17	22 000	20 000	5
10000 Hr.	–	–	–	–	–	–	–	–	–	–	–	–
700°F — 1/2 Hr.	12 000	10 000	29	–	–	–	14 000	13 000	9	19 000	18 000	4
100 Hr.	5 500	5 000	62	–	–	–	14 000	13 000	9	19 000	18 000	4
1000 Hr.	–	–	–	–	–	–	14 000	13 000	9	19 000	18 000	4
10000 Hr.	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 3

Creep and Stress Rupture Values for Aluminum Alloys at Elevated Temperatures

		7075-T6	2024-T4	2014-T6	2618-T61	X2219-T6	M237	M257(APM)	M276(APM)
		Stress, PSI, for Creep and Rupture							
212°F — Rupture in	1 Hr.	71 000	–	67 000	–	–	–	–	–
	10 Hr.	68 000	–	64 000	–	–	–	–	–
	100 Hr.	63 000	63 000	60 000	–	–	–	–	–
	1000 Hr.	56 000	59 000	58 000	–	–	–	–	–
Creep — 1.0% in	1 Hr.	63 000	–	59 000	–	–	–	–	–
	10 Hr.	59 000	–	58 500	–	–	–	–	–
	100 Hr.	56 000	–	58 000	–	–	–	–	–
	1000 Hr.	52 000	–	56 000	–	–	–	–	–
300°F — Rupture in	1 Hr.	57 000	–	57 000	53 000	–	–	–	–
	10 Hr.	49 000	–	52 000	49 000	–	–	–	–
	100 Hr.	37 000	52 000	49 000	44 000	–	–	–	–
	1000 Hr.	23 000	40 000	40 000	38 000	–	40 000	–	–
Creep — 1.0% in	1 Hr.	50 000	46 000	54 000	49 000	–	–	–	–
	10 Hr.	44 000	45 000	52 000	48 000	–	–	–	–
	100 Hr.	35 000	43 500	49 000	43 000	–	41 000	–	–
	1000 Hr.	22 000	39 000	40 000	–	–	40 000	–	–
0.5% in	1 Hr.	38 000	41 000	44 000	48 000	–	42 000	–	–
	10 Hr.	35 000	40 000	42 000	47 000	–	41 000	–	–
	100 Hr.	27 000	39 000	38 000	42 000	–	40 000	–	–
	1000 Hr.	20 000	–	34 000	–	–	38 000	–	–
400°F — Rupture in	1 Hr.	–	–	–	32 500	31 000	–	–	–
	10 Hr.	19 000	33 000	33 000	28 000	29 000	38 000	18 000	26 000
	100 Hr.	14 000	26 000	25 000	24 000	26 000	31 000	17 000	23 000
	1000 Hr.	9 600	18 000	14 000	21 000	24 000	25 000	16 000	20 000
Creep — 1.0% in	1 Hr.	19 000	–	35 000	29 000	29 000	–	18 000	–
	10 Hr.	17 000	–	33 000	25 500	26 000	–	17 000	24 000
	100 Hr.	13 000	21 000	24 000	21 500	24 000	27 000	16 000	22 000
	1000 Hr.	9 400	15 000	11 000	19 000	23 000	–	–	20 000
0.5% in	1 Hr.	18 000	–	35 000	28 000	27 000	–	17 500	25 000
	10 Hr.	16 000	24 000	33 000	24 500	23 000	30 000	16 500	23 000
	100 Hr.	12 000	19 000	24 000	21 000	20 000	26 000	15 000	21 000
	1000 Hr.	–	13 000	11 000	18 500	–	–	–	19 000
0.2% in	1 Hr.	16 000	24 000	35 000	27 000	23 000	31 000	15 000	21 000
	10 Hr.	12 000	20 000	32 000	23 500	19 000	27 000	14 000	20 000
	100 Hr.	9 500	14 000	21 000	20 000	–	–	–	–
	1000 Hr.	–	–	–	–	–	–	–	–
0.1% in	1 Hr.	12 000	20 000	32 000	26 000	19 000	27 000	–	–
	10 Hr.	9 900	14 000	27 000	22 000	–	–	–	–
	100 Hr.	–	–	16 000	19 000	–	–	–	–
	1000 Hr.	–	–	–	15 000	–	–	–	–
600°F — Rupture in	1 Hr.	–	–	–	10 000	–	–	–	–
	10 Hr.	–	7 000	5 000	7 500	14 000	11 000	13 000	15 000
	100 Hr.	4 400	4 400	3 500	5 000	9 500	8 700	11 500	14 000
	1000 Hr.	3 500	2 700	2 500	3 000	7 000	7 000	10 000	12 000
Creep — 1.0% in	1 Hr.	–	–	5 700	9 000	–	–	–	–
	10 Hr.	4 800	5 500	4 000	7 000	11 000	10 000	12 500	–
	100 Hr.	3 700	3 600	2 800	4 500	9 000	8 000	11 000	–
	1000 Hr.	2 700	–	–	2 500	–	–	10 000	–
0.5% in	1 Hr.	–	6 100	4 900	8 500	13 000	–	14 000	–
	10 Hr.	4 400	5 000	3 400	6 500	10 000	9 600	12 000	14 500
	100 Hr.	3 300	3 000	2 400	4 000	8 000	7 300	10 500	13 000
0.2% in	1 Hr.	5 000	5 500	4 000	7 000	10 500	11 000	11 000	14 000
	10 Hr.	3 800	3 300	2 800	6 000	8 500	7 500	10 500	12 000
	100 Hr.	–	1 800	2 000	3 000	6 700	–	–	–
0.1% in	1 Hr.	4 200	3 700	3 200	6 500	9 000	7 500		12 000
	10 Hr.	–	–	2 200	4 000	7 500	–		–

TABLE 4

Fatigue Properties of Some Aluminum Alloys at Elevated Temperatures

	7075-T6	2024-T4	2014-T6	2618-T61	X2219-T6	M237	M257 (APM)	M276 (APM)
	Fatigue Strength, PSI							
75°F — 10^4 Cycles	55 000	56 000	52 000	–	–	–	–	–
10^5 Cycles	40 000	43 000	39 000	36 000	–	–	–	–
10^6 Cycles	29 000	31 000	30 000	31 000	–	–	–	–
10^7 Cycles	24 000	24 000	24 000	26 000	–	–	–	–
10^8 Cycles	22 000	21 000	19 000	21 000	–	–	–	–
300°F — 10^6 Cycles	27 500	–	24 000	–	–	–	–	–
10^7 Cycles	21 500	25 000	19 000	–	–	–	–	–
10^8 Cycles	16 500	20 000	14 500	–	–	–	–	–
400°F — 10^6 Cycles	20 000	24 000	22 000	22 000	21 000	23 000	11 500	14 500
10^7 Cycles	14 000	18 000	15 000	17 000	15 000	17 000	8 500	11 000
10^8 Cycles	10 000	13 500	9 500	13 000	11 000	13 500	7 000	9 500
500°F — 10^5 Cycles	16 500	24 000	19 500	22 000	–	–	14 000	18 000
10^6 Cycles	12 500	17 500	14 000	17 000	–	–	10 500	13 500
10^7 Cycles	9 000	12 000	9 500	12 000	–	–	7 500	10 000
10^8 Cycles	8 000	9 000	6 000	9 000	–	–	6 500	8 500
600°F — 10^4 Cycles	–	19 000	15 000	25 000	22 000	24 000	17 000	22 000
10^5 Cycles	–	15 500	12 000	19 000	17 000	19 000	13 000	17 000
10^6 Cycles	–	12 000	9 500	14 000	12 000	13 500	9 500	12 500
10^7 Cycles	–	9 500	7 000	9 500	8 000	9 500	6 500	9 000
10^8 Cycles	–	8 000	5 500	6 500	5 500	6 500	5 500	7 500

yield strength of the -T4 and -T6 tempers are equivalent above a temperature of about 375°F. after heating about 10 hours which is the usual artificial aging treatment for this alloy. The same is true after 100 hours. From Table 2 it will be observed that at 300°F. and lower, alloy 2014-T6 appears to be stronger than 2024-T4. The curves of tensile yield strength (Figures 3 and 4) cross after 100 hours at 390°F. and after 1,000 hours at 325°F. At 400°F. and higher, alloy 2024-T4 is, in general, superior in strength to 2014-T6, the exception being the yield strength after ½ hour at 400°F. and 500°F.

The creep and stress rupture properties are more complicated. From Table 3 it would seem that at 300°F., alloy 2014-T6 has an advantage over 2024-T4 in creep. In stress rupture at this temperature, these two alloys are comparable. At 400°F., alloy 2014-T6 continues to show an advantage in creep over 2024-T4 and is comparable in stress rupture, except in both properties 2024-T4 shows some superiority for longer times. At 600°F., 2024-T4 shows an advantage in both creep and stress rupture over 2014-T6. Referring to Table 4, 2024-T4 is shown to have an advantage over 2014-T6 in fatigue strength. Data for 2024 in the -T6 temper are not available for creep, stress rupture and fatigue, but these properties should not differ appreciably from those of the -T4 temper after artificial aging has taken place during heating.

To sum up so far, it would seem that the characteristics of 2014-T6 and 2024-T6 or 2024-T4, after heating at temperatures and times in excess of those required to complete artificial aging, are similar and except as noted previously there is little to choose between these two alloys for elevated temperature service. It will be convenient, therefore, to consider these alloys as a basis for comparison.

The aluminum-magnesium-zinc-copper alloys may be discussed briefly using 7075-T6 as typical of their behavior at elevated temperatures. Figure 3 shows that after 100 hours at temperature 7075-T6 loses its strength advantage at about 250°F. Figure 5 clearly shows how rapidly this product loses its strength at 300°F., and at 600°F. (Figure 6) it is at the bottom of the list after ½ hour, although at this temperature 2024 and 2014 are not greatly different, especially after 100 hours. These aluminum-magnesium-zinc-copper alloys are not recommended for service at temperatures above 250°F.

Alloy 2618-T6, which at present is used only for forgings, is very close in elevated temperature properties to 2014 and 2024. Its tensile yield strength is slightly higher at 400° to 500°F. after about 100 hours at temperature (Figure 3). At 400°F., its creep and stress rupture strengths are in general comparable with those of 2014 and 2024 alloys (Table 3). At 600°F., however,

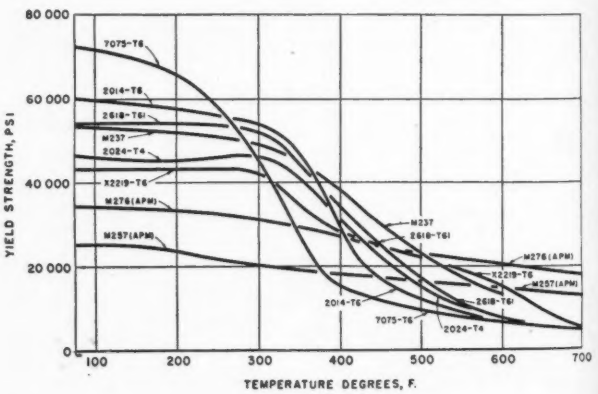


Figure 3

Yield strength of wrought alloys at elevated temperatures after 100 hours at temperature

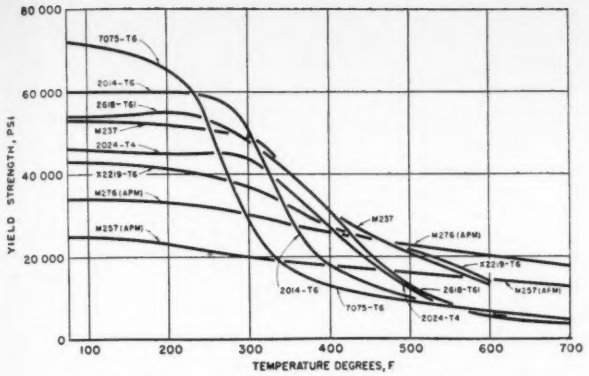


Figure 4
Yield strength of wrought alloys at elevated temperatures after 1,000 hours at temperature

its creep and stress rupture characteristics are definitely superior to those of 2014 and 2024. In fatigue strength (Table 4), it lies between 2014 and 2024 at 400°F. and 500°F. and is superior to both at 600°F. for a life up to a million cycles.

Next in order of interest with increasing temperature is alloy M237. The tensile yield strength of this alloy after 100 hours at temperature is highest from about 375° to 500°F. (Figure 3) of any of the alloys tested. Its greater stability at 300°F. is clearly shown by Figure 5 where its yield strength after 10,000 hours at temperature is some 8,000 to 10,000 psi higher than for 2014 or 2024 and several thousand psi higher than for 2618-T6. At 300°F., its creep and stress rupture strengths are comparable to 2014 and 2024. At 400°F., its creep strength is also comparable but its stress rupture strength is the highest of any of the alloys tested. At this temperature, its fatigue strength ranks with 2024-T4 and 2618-T61. At 600°F., it is on a par with 2618-T61 and superior to 2024-T4 up to a life of a million cycles.

With further increase in temperature level, X2219-T6 should be considered. Referring again to the tensile yield strength curves of Figures 3 and 4, it will be seen that

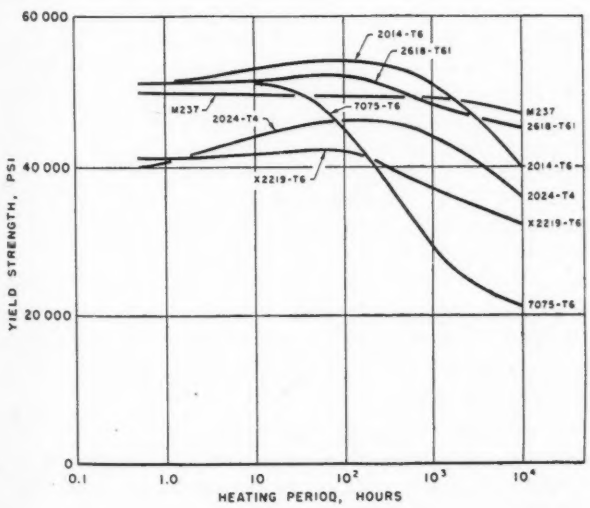


Figure 5
Change of yield strength with time at 300°F.

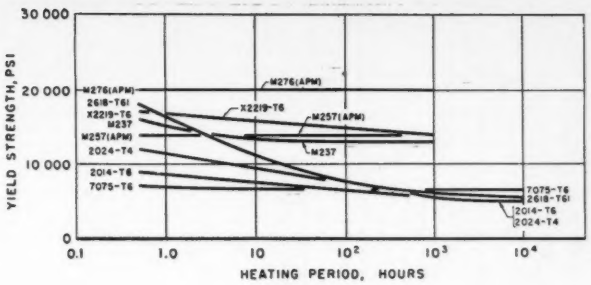


Figure 6
Change of yield strength with time at 600°F.

X2219-T6 shows a slight superiority in tensile yield strength over M237 after 100 hours of heating at 525° to 600°F. and is comparable after 1,000 hours of heating at 475° to 600°F. This superiority in tensile yield strength at 600°F. is again illustrated in Figure 6, although the difference seems to decrease with increasing time at temperature. In creep and stress rupture strength (Table 3), M237 is superior to X2219-T6 at 400°F., but at 600°F. alloy X2219-T6 shows a slight superiority. In fatigue strength (Table 4), X2219-T6 is nearly as good as M237 or 2618-T61 at both 400°F. and 600°F.

As was stated in the introduction, the aluminum powder metallurgy products are in a class by themselves in their behavior at elevated temperatures. Figures 3 and 4 show how well the tensile yield strengths of these products hold up with increasing temperature, and Figure 6 shows their remarkable stability at 600°F. In tensile yield strength, the APM product, M257, shows marked superiority at temperatures above 625°F.; the less ductile product, APM M276, shows an even greater superiority at temperatures above 500°F. In creep and stress rupture, these products again show superiority at 600°F. over all of the alloys produced by conventional processes. The fatigue characteristics of M257 are, in general, inferior to those of the conventional alloys even at 600°F. Alloy M276 shows improved fatigue characteristics over M257, and at 600°F. it is substantially equivalent to the best of the conventional alloys. It is of interest that there is much less difference in the fatigue strength of these APM products at 600°F. as compared with 400°F. than for conventional products. The APM

TABLE 5
Thermal Conductivity of Some Aluminum Alloys

Alloy	Thermal Conductivity at 25°F (77°F), CGS Units
Wrought	
7075-T6	0.29
2024-T4	0.29
2014-T6	0.37
2618-T61	0.37
X2219-T6	0.32
M237	0.32
M257 (APM)	0.46
M276 (APM)	0.37
Sand Cast	
355-T51	0.40
A355-T51	0.40
142-T77	0.36
XA140-F	0.23

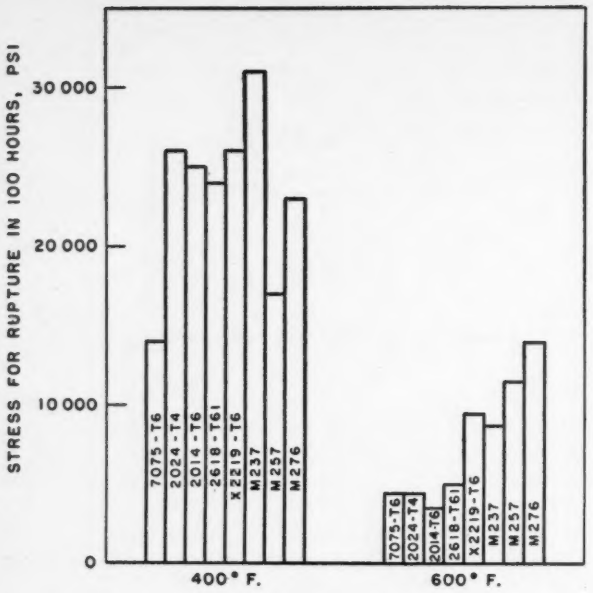


Figure 7
Stress for rupture in 100 hours

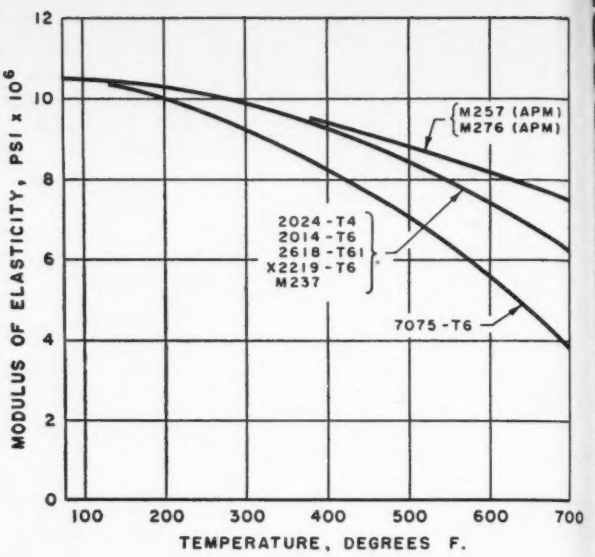


Figure 8
Modulus of Elasticity

product, M257, has the highest thermal conductivity of the wrought materials discussed (Table 5).

The bar graph of Figure 7, comparing the stress rupture strengths in 100 hours at 400°F. and 600°F., gives a good visual comparison of the wrought products just discussed. It emphasizes the superior stress rupture strength of M237 at 400°F.; and of X2219-T6, M237 and the APM products, M257 and M276, at 600°F.

The modulus of elasticity is an important design property for structural applications where buckling may occur. The modulus decreases with increasing temperature as is illustrated by Figure 8. It was found possible to show the effect of temperature on the modulus of elasticity in a single curve for all of the airframe alloys produced by conventional methods except 7075-T6. This alloy shows the greatest loss in modulus of elasticity, but this is of little importance since for other reasons it probably should not be used in service above about 250°F. The APM products, M257 and M276, may also be illustrated by a single curve which is above that for the conventional alloys.

Resistance to Corrosion: Wrought Alloys

The resistance to corrosion of X2219 and M237 alloys has been evaluated in a preliminary way by tests of 0.064 in. thick sheet alternately immersed in a 3.5% sodium chloride solution (10 min. immersion in each hour) for periods up to 26 weeks. This test included unstressed specimens, specimens stressed to three-quarters of the yield strength and specimens preformed and then highly stressed. There were no stress corrosion failures and little acceleration of loss in tensile strength in the stressed specimens. The alclad specimens of both alloys showed no loss in tensile strength either stressed or unstressed in this period of exposure.

In this test, these new alloys showed a somewhat higher loss in tensile strength in the unstressed condition than the 2024-T3 specimens included for comparison, but the losses of the stressed specimens were somewhat lower than those of 2024-T3. In a single comparison on ⅛ in. diameter specimens cut in all three directions from 2 in. x 3 in. forged bar and stressed to three-quarters of the yield strength, none have cracked after 12 weeks in the alternate immersion test previously described.

From these limited tests, it is estimated that the resistance to corrosion of these two new alloys would be of the same order as that of 2024.

The resistance to corrosion of the APM products is of a high order, substantially equivalent to that of commercially pure aluminum. These products have shown no evidence of susceptibility to stress corrosion cracking.

CASTING ALLOYS

There are three standard casting alloys being used for elevated temperature service and one experimental alloy of the "X" status. The oldest alloy, 142, is the British "Y" alloy of World War I. It has stood the test of time because of its good elevated temperature properties. Alloys 355 and A355 are of the aluminum-silicon-magnesium-copper type and hence have excellent casting characteristics. Alloy A355 contains, in addition to the elements mentioned, 0.8% of both manganese and nickel. The new alloy, XA140,[e] contains high copper (8.0%) and magnesium (6.0%) with the addition of 0.5% of each manganese and nickel. At 600°F. this new alloy exhibits tensile and fatigue strengths superior to those of other commercial aluminum casting alloys. It is also outstanding in its resistance to loss of tensile properties upon prolonged heating.

Data: Casting Alloys

The nominal composition of the casting alloys having the best properties for elevated temperature service is shown in Table 6. The tensile properties at room temperature and when tested at temperatures up to 700°F.

[e]Patent pending.

TABLE 6
Nominal Compositions of Cast Aluminum Alloys

	355	A355	142	XA140
Cu	1.3	1.4	4.0	8.0
Si	5.0	5.0	–	–
Mn	–	0.8	–	0.5
Mg	0.5	0.5	1.5	6.0
Ni	–	0.8	2.0	0.5

after ½, 100, 1,000 and 10,000 hours at temperature are shown in Table 7. The marked superiority of the experimental alloy XA140-F in tensile and yield strengths is clearly illustrated. Although strictly comparable data on creep and stress rupture strengths are not available, it may be inferred from such tests as have been made that this alloy is superior to the other alloys at 400°F. but not at 600°F. The fatigue strength of the new alloy at 400°F. and 600°F. appears to be markedly superior to the other casting alloys.

To summarize the comparison of casting alloys, it may be said that the new alloy XA140-F is markedly superior to the other available alloys in tensile, tensile yield strength and fatigue at temperatures of 400°F. and 600°F. At 400°F., it is superior in creep and stress rupture strength. The alloy has sand casting characteristics somewhat superior to those of alloy 142. A tendency to hot cracking, however, may place limitations on the types of castings which may be made in permanent molds. It should be noted that, for applications where thermal conductivity is important, the lower thermal conductivity (Table 5) of this alloy should be given consideration.

Resistance to Corrosion: Casting Alloys

Of the casting alloys, the resistance to corrosion of alloys 355 and A355 is the highest of the group with alloy 142 being lower; alloy XA140, judging from its chemical composition, would have a resistance to corrosion comparable with or slightly lower than alloy 142.

CONCLUSION

The author has presented data on one new casting alloy, two new wrought alloys, and two APM products as well as on a forging alloy which has not been used for airframe structures. It has been indicated that the high strength aluminum-zinc-magnesium-copper alloys as typified by 7075-T6 are not efficient for airframe structures at temperatures above 250°F. The standard airframe alloys, 2024 and 2014, appear to be appropriate for temperatures in the range of 250°F. to 350°F., alloy 2014-T6 having a small advantage in tensile, stress rupture and creep strengths and 2024-T4 in fatigue strength. Within this same range of temperature and up to about 450°F., alloy 2618-T61 deserves consideration, but its possible choice depends on the specific governing property and the time. In the temperature range 350°F. to 500°F., the experimental alloy, M237, should be considered where strength, creep, stress rupture and fatigue properties are important. From 500° to 650°F., the alloy X2219-T6 has some important advantages in creep and stress rupture. Above 600°F., the APM products show marked superiority over any of the conventionally produced alloys.

TABLE 7
Tensile Properties of Some Sand Cast Alloys at Elevated Temperatures

	355-T51			A355-T51			142-T77			XA140-F		
	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %	Tensile Strength, PSI	Yield Strength, PSI	Elong. in 2 In., %
Room Temperature	28 000	23 000	1.5	28 000	24 000	1.5	30 000	23 000	2.0	34 000	29 000	1.0
212°F — 1/2 Hr.	28 000	22 000	1.5	28 000	23 000	1.5	30 000	23 000	2.0	–	–	–
100 Hr.	28 000	22 000	2.0	27 000	23 000	1.5	30 000	23 000	2.0	–	–	–
1000 Hr.	28 000	22 000	2.0	27 000	23 000	1.5	30 000	23 000	2.0	–	–	–
10000 Hr.	28 000	22 000	2.0	27 000	23 000	1.5	30 000	23 000	2.0	–	–	–
300°F — 1/2 Hr.	26 000	21 000	2.0	26 000	21 000	1.5	29 000	22 000	2.0	–	–	–
100 Hr.	26 000	20 000	2.0	25 000	20 000	1.5	29 000	22 000	2.0	–	–	–
1000 Hr.	25 000	20 000	2.0	24 000	20 000	1.5	28 000	22 000	2.0	–	–	–
10000 Hr.	24 000	19 000	3.0	24 000	20 000	2.0	27 000	21 000	2.0	–	–	–
400°F — 1/2 Hr.	22 000	18 000	3.0	22 000	18 000	2.0	26 000	19 000	2.0	31 000	27 000	0.5
100 Hr.	20 000	16 000	3.0	19 000	15 000	3.0	23 000	17 000	2.0	37 000	30 000	0.5
1000 Hr.	17 000	14 000	5.0	18 000	13 000	3.0	22 000	16 000	2.0	35 000	28 000	1.0
10000 Hr.	14 000	10 000	8.0	17 000	12 000	4.0	20 000	15 000	3.0	–	–	–
500°F — 1/2 Hr.	15 000	14 000	5.0	17 000	14 000	4.0	21 000	16 000	2.0	–	–	–
100 Hr.	12 000	10 000	10.0	13 000	9 500	6.0	17 000	13 000	3.0	–	–	–
1000 Hr.	10 000	7 500	13.0	12 000	8 000	8.0	15 000	10 000	4.0	–	–	–
10000 Hr.	9 500	5 000	16.0	11 000	7 000	10.0	13 000	8 000	6.0	–	–	–
600°F — 1/2 Hr.	9 500	8 500	13.0	12 000	8 500	9.0	15 000	11 000	4.0	20 000	16 000	25.0
100 Hr.	7 000	5 000	24.0	9 000	6 000	9.0	11 000	7 500	4.0	20 000	14 000	25.0
1000 Hr.	6 000	4 000	30.0	8 500	5 500	9.0	9 500	5 500	12.0	19 000	14 000	25.0
10000 Hr.	6 000	3 000	36.0	7 500	5 000	10.0	8 000	4 000	20.0	–	–	–
700°F — 1/2 Hr.	5 500	4 500	25.0	7 000	5 000	10.0	9 000	6 000	8.0	13 000	7 500	48.0
100 Hr.	4 500	3 000	40.0	6 500	4 500	10.0	6 000	4 000	30.0	10 000	6 500	62.0
1000 Hr.	3 500	2 000	45.0	6 000	4 000	12.0	5 000	3 500	35.0	–	–	–
10000 Hr.	3 500	2 000	50.0	6 000	4 000	15.0	5 000	3 000	40.0	–	–	–

It is important both to the aircraft industry and to the aluminum industry that the new alloys mentioned should be evaluated promptly to determine whether or not their properties justify their commercial production for use for airframe structures. The new casting alloy XA140 is at present available only for experimental use. Alloy 2618 is now available as forgings only. Are its elevated temperature properties such as to require it in the form of sheet, alclad sheet, plate and extrusions? Alloy X2219 is also available for experimental use in the form of extrusions and forgings. It remains to be determined whether there will be a substantial requirement for this alloy in the form of sheet and plate and alclad sheet. Alloy M237 is still further from commercialization, but the aluminum industry would like to know whether its elevated temperature characteristics would justify its development for sheet, alclad plate, extrusions and possibly forgings.

The aluminum industry is willing and anxious to do its share in developing these new products but it needs the guidance of the aircraft industry. The introduction of a new alloy or product for aircraft service requires an extensive program of evaluation and development. Neither the aircraft nor the aluminum industry can afford this effort unless there seems to be a reasonable chance that the new products will represent a significant improvement over the standard airframe products now available.

ACKNOWLEDGMENT

The Cleveland Research Division of the Aluminum Research Laboratories was responsible for the development of the new alloy composition, XA140, and Mr. Charles B. Criner and Mr. J. Paul Lyle of the Aluminum Research Laboratories, New Kensington, Pa., for the development of alloys X2219 and M237, and the aluminum powder metallurgy products, respectively. The data on mechanical properties were obtained and organized by the Mechanical Testing Division, Aluminum Research Laboratories, New Kensington, under the supervision of Mr. F. M. Howell, Chief of the Division. The author expresses his sincere appreciation for the very active help of Messrs. F. M. Howell and K. O. Bogardus in preparation of this paper and of Mr. Robert Malcolm for the preparation of the figures and tables.

REFERENCES

[1]Metal Progress, Vol. 67, No. 3, pp. 85-89, March, 1955.
[2]Journal of Metals, Vol. 1, No. 3, pp. 443-447, March, 1955.

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THE TIME FACTOR IN AIRCRAFT DEVELOPMENT†

by Group Captain H. R. Foottit*

Royal Canadian Air Force

ALTHOUGH the time factor in aircraft development is largely a function of the aircraft companies, and their suppliers, the aircraft operator gains some direct experience in this line since he uses, and often waits for, the final product. Moreover, from published data it is possible to assemble some statistical information which indicates the experience of others. In Canada, the R.C.A.F. has had some limited, direct experience. From all these sources it is possible to put together a time history of various aircraft projects, come to some conclusions on the time factor in airplane development, and explore possible ways of improving the situation.

The data presented herein can be divided into three categories:

(a) General times taken to develop specific types of aircraft:

(b) The RCAF's experience with the Avro Canada CF-100 jet fighter:

(c) Possible means of improving the time factor in development.

THE TIME PHASES

Two time phases in the design and development of aircraft are considered separately: (Figure 1)

(a) Phase 1: "*Design Phase*": extending from the issue date of the specification, to the date of the first flight of the first aircraft:

(b) Phase 2: "*Development Phase*": extending from the date of the first flight of the first aircraft, to the delivery date of the first aircraft essentially meeting the specification requirements.

It should be noted that the only really positive date of these three is the "first flight of the first aircraft". The specification issue date may seem fairly positive, but in practice many aircraft companies start work before this – either on their own initiative, or spurred on by advance information given to them by the customer. The last date, delivery of the first aircraft that essentially meets the requirement, is also not too certain. There are "degrees" or "shades" of satisfaction: the manufacturer may fall slightly short of the specification in certain performance criteria, or the customers may have altered certain criteria. Hence, there is always some doubt concerning this date.

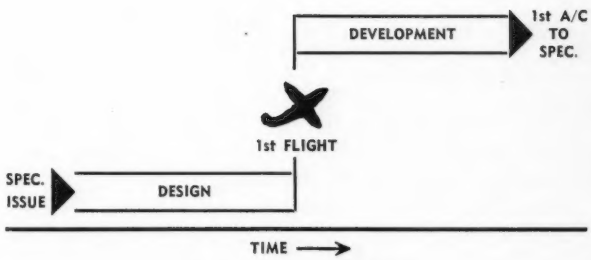


Figure 1. Basic Phases

Taken as a whole, then, the terminal dates are not too positive. Yet taken on an average, the development time periods devised are reasonable estimates from the available statistical data, and can be very useful for planning purposes, and as a yardstick for measuring progress.

DESIGN PHASE

Phase 1, the Design Phase, may be further broken down into three sub-phases for consideration: (Figure 2)

(a) *Preliminary Design*: from the specification issue date, to the date the manufacturer submits his proposed design to the customer.

(b) *Customer Consideration*: from the time the customer receives the proposed design, to the date he gives the "go-ahead" to the aircraft contractor.

(c) *Detail Design*: from the time the contractor has the approval to proceed, to the first flight of the first aircraft.

Preliminary Design

In the Preliminary Design sub-phase there are a number of variables that affect the time. The first is the existing work load in the company. The Engineering Department may already be working on one or more airplanes, in design, development, or production development. It takes time and planning to get the personnel into the new project. There is also a variable in the effort the company decides to expend on the proposal. This factor may well be influenced by whether, or not,

†Paper read before the Ottawa Branch of the C.A.I. on the 12th October 1955.

*Director of Aircraft Engineering.

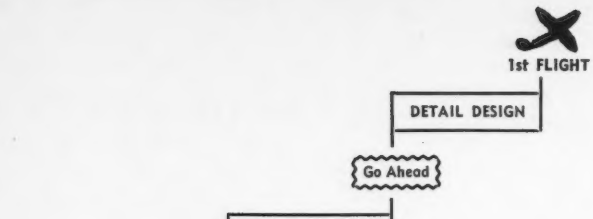


Figure 2. Design Phase

Figure 3. Design Phase Time

they are being paid for the study; whether, or not, they will do some wind tunnel tests to confirm some preliminary aerodynamic calculations; and other such decisions. There is also the size and complexity of the airplane to consider. In general, it takes longer to make up a proposal for a large, complicated airplane, than it does for, say, a simple two place trainer.

Considering all variables, however, statistical evidence indicates that the minimum time in this Preliminary Design phase, is 3 months. The maximum time is approximately 9 months.

Customer Consideration

When the customer receives the proposal, there is also a number of variables that affect the time he will take to look it over before he decides to proceed. To mention a few: the urgency on getting the airplane into service; the availability of funds – when he sees the contractor's final estimate; the complexity of the airplane which may call for extensive study and even advice from outside agencies.

Considering all these variables, statistical evidence indicates that the time period for this Customer Consideration sub-phase, is a minimum of 3 months. The maximum appears to be about 1 year.

Detail Design

In the Detail Design sub-phase, after the manufacturer has an authorization to proceed, there are also variables. The other work in the plant, the availability of personnel, and the size and complexity of the aircraft, are probably the most important.

From statistical data, the variations in time during this period must be broken down depending on the type of aircraft. Taking a range of these, the Detail Design sub-phase is as follows:

Small jet trainer	2	years
Small transport	2	years
Large transport	3	years
Jet fighter	3½	years
Jet bomber	4	years

Total Design Phase

Since it was previously established that the Preliminary Design sub-phase took from 3 to 9 months, and the Customer Consideration sub-phase from 3 months to 1 year, we can now add these to the Detail Design sub-phase, and arrive at some totals.

These are as follows: (Figure 3)

Aircraft Type	Design Phase Time–Years		
	Minimum	Maximum	Approx Average
Small jet trainer	2½	3¾	3
Small transport	2½	3¾	3
Large transport	3½	4¾	4
Jet fighter	4	5¼	4½
Jet bomber	4½	5¾	5

In looking over actual data on existing airplanes, it becomes very apparent that no airplane ever proceeds in accordance with the manufacturer's carefully laid down time-table which he submits when the design starts. As one person expressed it, "There is *always* a story behind each time schedule, as it finally turns out after the design and development is finished". In some cases the manufacturer ran into more technical trouble than he anticipated. In other cases, the customer changed the requirement when he was partly through the design.

The R.C.A.F.'s experience with the CF-100 fighter, which is now the standard all-weather fighter in the air defence of Canada, also falls into this category. In the first place, the specification was issued at the close of the last war, when there was considerable confusion both in the service and in the aircraft companies. Secondly, a contract was let to A. V. Roe Canada, Ltd., for the design and development of this airplane, while the company was just being formed from the ashes of Victory Aircraft Ltd., a government company.

The original letter of intent for the CF-100 was issued on November 3, 1945. Avro managed to collect enough engineering personnel together to make a proposal on the aircraft in August 1946. The R.C.A.F., in the meantime, had been trying to settle on a number of major requirements – which resulted in numerous changes in the specification. However, the final arrangement was agreed to and the Detail Design phase started in October 1946. The first flight of the first aircraft took place in January 1950. Hence, the total Design Phase extended for a period of 4 years, approximately. This is in line with the general figures, and though

slightly higher, when the "story" of a new company, a new design and development industry, and a new task for the R.C.A.F., are all added together, it is really quite an impressive record.

DEVELOPMENT PHASE

As previously outlined, Phase 2, the Development Phase, extends from the first flight of the first aircraft to the date when the first aircraft is delivered which essentially meets the specification requirements.

It is unusual, I believe, to quote this latter date as the termination of the design and development period. More often, the date published is the first production aircraft delivery date. I think, however, that the date selected is the one that most interests the customer, and is, in fact, the end of the overall development phase. The aircraft, of course, continues on, being steadily modified and improved, through what might be called "production development."

It should be pointed out, however, that production aircraft are being accepted before this date. (Figure 4) In this day and age of complicated airplanes it is advantageous to do so.

A number of aircraft will be required by the manufacturer for development flying; if the Air Force is the customer it will require airplanes for testing and crew training, to ensure that it can make the best possible use of the final product in a tactical sense; if an airline is the customer, it will require airplanes for testing, crew training, and route proving. These airplanes that come out before the first aircraft which meets the specification, will undoubtedly require modification if they are to be used operationally. But they are still of great value to the contractor and the customer. Consequently, it can be assumed that production is already under way when the first aircraft that essentially meets the specification requirements is delivered.

From statistical data, and using the same aircraft types as before, the Development Phase is as follows:

Small jet trainer	1 year
Small transport	1½ years
Large transport	3 years
Jet fighter	3½ years
Jet bomber	4 years

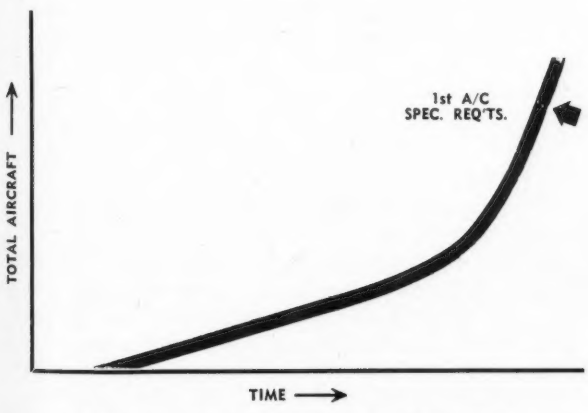


Figure 4. Development Phase—Production

As previously pointed out, from R.C.A.F. experience with the CF-100, the Design phase ended on January 1950, the first flight of the first aircraft. This is also the beginning of the Development Phase.

The second aircraft had its first flight in July, 1950. Then there was a small, pre-production run, followed by large scale production. The first airplane that approached the R.C.A.F. requirements occurred in the middle of the CF-100 Mark 3 order, or the beginning of the Mark 4 run – depending on the "degree" of operational effectiveness assumed.

The first of the Mark 4 aircraft was accepted in October 1953. However, owing to various troubles, such as the necessity to change all the hydraulic pumps, the aircraft was not delivered for service use until early 1954. Consequently, it can be said that this period, the Development Phase of the CF-100, ran about 4 years. This, however, uses the first Mark 4 as a baseline. If you consider the Mark 3 aircraft, the period would be about 3 years. On the average, then, this phase was about 3½ years.

DESIGN PLUS DEVELOPMENT

To return to the general averages for all aircraft again, we can now add the Design Phase to the Development Phase. These figures are as follows: (Figure 5)

Aircraft Type	Time Factor—Years		
	Design Phase	Development Phase	Total
Small jet trainer	3	1	4
Small transport	3	1½	4½
Large transport	4	3	7
Jet fighter	4½	3½	8
Jet bomber	5	4	9

Looking at the CF-100 development, it is apparent that it is similar to the above, since the Design Phase was 4 years, the Development Phase averaged 3½ years, for a total of 7½ years.

As a side light to this development time factor it is interesting to see how the assembly of statistical data, which we can obtain for aircraft, is practically nonexistent for missiles. Consequently there are innumerable

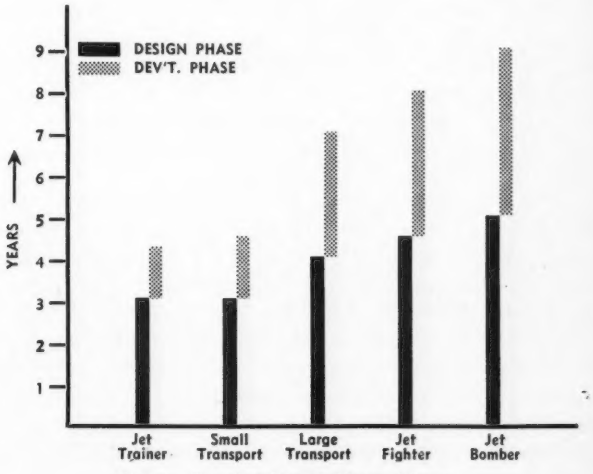


Figure 5. Combined Phase Times

arguments within the armed services as to operational missile dates. There are, of course, as many types of missiles as there are airplanes. And only a few, such as Nike and Matador, have been announced as operational. In due time we will have some statistical data on missiles, and with it a lot better idea on development times. But until more missiles are designed, developed, and used, so we can assemble the data, the arguments will continue.

IMPROVING THE TIME FACTOR

In the meantime, is it important to reduce aircraft development times? In a symposium on aircraft production, held in England in 1952, Mr. W. C. Puckey of the Ministry of Supply pointed out "It (time) is the essence of customer satisfaction". This is certainly true. For the civil operator, it means fewer long range worries, for he knows he can get his equipment in a reasonable time after he needs it. For the Air Force, it means that a counterweapon is available shortly after a threat appears over the horizon. The problem is simplified and we have better security. It is important, then, that we should look at possible ways of cutting down this development time period.

Two factors appear basic in this task:

(a) *Knowledge*:

(b) *Initiative*:

Knowledge can be accumulated in the Design Phase, for example, by specialization of companies: in other words, certain companies will specialize on the design and development of fighters, others on bombers, others on large transports. Thus they will get the "feel" for the job, and accumulate the knowledge necessary for quick action. This is not a new thing. The steel companies, in the past, have consolidated their resources, and then specialized on certain phases of steel fabrication within certain companies. The end result has been, I understand, better and cheaper fabricated steel products.

There is some indication that this process is now going on, in the early stages, in the U.S. A recent press release mentioned that contracts had been let to three U.S. companies for a long range fighter, on the basis that these companies were best fitted to do the job. One or more of them is to be selected for finishing the complete aircraft, though the present contract only goes to the "mock-up" stage. Selection of the initial three companies is certainly specialization.

In the Development Phase, knowledge can be accumulated quickly by ordering initially a number of test airplanes. Tests can then proceed concurrently instead of consecutively.

This scheme is being used in the U.S. (Cooke-Craigie System) and the U.K. (Development Batch System). The initial contract is not for 2 prototypes, as it has been in the past, but for a number of aircraft on a production line basis right from the start. For a small trainer or small transport the initial order might be for 5 to 10 aircraft; for a large transport, 10 to 15; for a jet fighter, 25 to 50; for a jet bomber 15 to 20. With such schemes as this, it is possible for the company and the customer to speed up the development phase through the accumulation of knowledge. Definite results from this system are not yet available, but it appears to be a step in the right direction.

To speed up both the Design Phase and the Development Phase, "company initiative" can play a major role. The question, then, is how to promote it. History shows us that one of the greatest driving forces in the development of the world has been the "profit motive". However, in the design and development of military aircraft the costs are so high that democratic governments clamp a rigid control on the manufacturer's profit. One can argue then that we must re-create a profit motive in the industry, and initiative will follow.

At present, it is almost impossible to get any company to take a fixed price development contract, at a reasonable price, yet one where the "profit motive" might prevail. The reason, of course, is that most of these developments are too expensive. The development of a jet airliner, for example, may well cost more than the capital investment of the company that proposes to build it. And there are too many unknowns on the engineering side, so that a company can run into considerable technical trouble that was unplanned for in the budget. As a result most contracts for design and development are on some "cost-plus" basis.

There is possibly some justification for the average company's outlook. A recently released document, "Percentage Profits, based on Sales and After Taxes" for the average U.S. airframe manufacturer shows the following:

Year:	1944	Profit:	1.1%
	1945		2.1
	1949		3.0
	1954		3.8

These are apparently not high enough to allow the company to engage in high risk programs, such as aircraft development on a fixed price basis that is within reason.

Two procedures could possibly be adopted, for example, that might induce the manufacturer to take a fixed price contract. One of these is a development policy that permitted shorter design steps. Instead of jumping from a subsonic Mach .85 fighter to a supersonic Mach 2.0 fighter, we should try a number of small steps in between. These intermediate steps would produce a number of test aircraft, though the airplane may never go into full-scale production. The other scheme might be to allow the manufacturer an extra profit, over and above his normal one on an existing production contract, on a tax arrangement whereby he could keep the money if he invested a certain percentage of it in design and development.

The economics of these profit schemes would undoubtedly have to be worked out in some detail by the people that are competent to do them. They are only offered as suggestions. However, considering the present time period in the development of military and civil air power, it is far too long. We need new ways to improve the situation. For, in the end, I believe that we will get better air power sooner, and at a lower cost, if we develop the right system to do it.

AIRCRAFT ACCIDENT INVESTIGATION†

by Group Captain R. C. Davis*

Royal Canadian Air Force

THE Daniel and Florence Guggenheim Aviation Safety Center have set forth a number of precepts for aircraft design in an excellent booklet entitled *Design for Safety*. My duty involves a constant study of aircraft accidents, both here and abroad, and I should like to explore certain of these precepts in detail. Their importance to the designer cannot be over-emphasized.

PRECEPT 1.

Procedures for adequate maintenance and operating practices established by designers should be consistent with average human effort, ability and attitude.

The Situation

A pilot rolled his aircraft to the inverted position and almost immediately the engine flamed out. Normally ten to twelve seconds of engine operation could be expected while inverted. The pilot returned the aircraft to the upright position and made a forced landing. Although he escaped injury the aircraft was destroyed.

Investigation

Investigation revealed that the negative G valve in the fuel system had been incorrectly installed following a main fuel tank change.

The Hazard

The G valve lever had been designed in such a manner that it could be installed in the reverse position, in which case it was not readily apparent that the valve did not seat properly. In this condition, the engine would be starved of fuel almost immediately after the aircraft was inverted.

The Fix

A fix was not authorized in this case as the aircraft type was being phased out of service. I am sure that there would have been no difficulty in redesigning the lever to prevent its assembly in the reversed position.

PRECEPT 2.

The aircraft and its components must be protected against the effects of normally inadvertent or uncontrollable human errors or carelessness.

†Paper read at the I.A.S./C.A.I. International Meeting in Ottawa on the 4th November 1955.

*Director of Flight Safety

Case 1

The Situation

An aircraft of a particular type was seen to suddenly dive into the ground from level flight. The pilot was killed and the complete destruction of the aircraft precluded determining the cause from evidence in the wreckage.

Investigation

Investigation was concentrated on the fore and aft control system in the aircraft type. Runaway trim and foreign objects were suspected as cause factors. An investigation of a pilot's report on the same type of aircraft in which sticking fore and aft control was experienced directed attention to the method of fastening an inspection fairing to the fuselage adjacent to the stabilizer power control unit. Seven screws were used and instructions called for one to be used in a specific hole to be shorter than the other six in order that it wouldn't interfere with the movements of a lever in the fore and aft control system. One of the longer screws was found in the critical hole which explained the pilot's complaint. The use of long screws was believed to have caused the previous accident referred to.

The Hazard

Replacing an inspection panel or fairing should be a simple matter and not one liable to create a major hazard by causing interference with critical flight controls.

The Fix

The fix in this case was to blank off the hole in the fairing which required the short fastening screw.

Case 2

The Situation

After completing a sharp turn, a dive and a pull-up at relatively low level, an aircraft suddenly dived into the ground. The pilot was killed and again complete destruction of the aircraft precluded obtaining evidence that would establish the cause. Runaway trim and foreign objects were suspect.

Investigation

This particular type of aircraft is fitted with electrically operated trim controls. A junction box contains a number of electrical terminals for the wiring including

that which leads to the trim motors. A loose piece of metal inside it would be sufficient to short two adjacent electric terminals which in turn would give a full deflection of one set of trim tabs causing a violent manoeuvre of the aircraft. All that was required to initiate the trouble was for the pilot to manoeuvre the aircraft in a manner which would dislodge a washer or wire clipping from a crevice in the box and cause it to short two electric terminals in the control system. If it occurred at low altitude the pilot would not have sufficient time to take recovery action.

The Hazard

Where electrics form part of a critical flight control system, the shorting of terminals by foreign objects mislaid or left in the adjacent area may be sufficient to cause a fatal accident and/or the loss of an aircraft. A one quarter inch length of wire or a washer, the diameter of a pencil, may do the trick.

The Fix

The fix in this case was to insulate the electric terminals in the junction box.

Case 3

The Situation

During a night flight on instruments the passengers in a small transport type aircraft requested an adjustment of the cabin heat. The pilot adjusted a control. Shortly afterwards an engine seized and an emergency landing was successfully made.

Investigation

The control pedestal of this type of aircraft contains three controls within four inches of each other. The control knobs are approximately the same shape and size. Two of the controls are for cabin heat adjustments and the third when activated shuts off the supply of oil to one engine.

Investigation revealed that the engine had seized due to oil starvation and that the oil shut off valve had been activated. The pilot with his attention concentrated on instrument flying in a darkened cockpit had inadvertently selected and pulled the oil shut off valve control instead of that for the cabin heat.

The Hazard

Controls located necessarily in close proximity due to space limitations, having critical and different functions and fitted with similar knobs expose the pilot to the hazard of inadvertent operation. The risk is particularly high when the pilot's attention is distracted during instrument flight at night with the cockpit lights dimmed.

The Fix

The interim fix in this case was to fit a soft metal strap over the oil shut off valve control which is used only in the case of an inflight engine fire. The value of shape coding for aircraft controls to minimize the probability of pilot error in control selection by simplifying discrimination processes is reasonably well known.

PRECEPT 3.

Design structures and mechanism to function safely and dependably over long periods of repeated use.

The Situation

Immediately after take-off, an aircraft rolled to the right and after reaching ninety degrees of bank, altitude was lost and the aircraft struck the ground partially inverted. There is a power boost system using hydraulic pressure to supplement manual pressure on the aileron control system in this type of aircraft. Operation is such that the pilot retains feel of the control yet is able through servo action to produce a much greater force on the aileron than is applied at the control stick. The power unit consists essentially of an actuating cylinder and a control valve with the necessary linkage. It also incorporates a debooster cartridge which reduces stick sensitivity at low aileron loads. Within the cartridge a spring is held in place by an internal circlip.

Investigation

On investigation it was found that the circlip had come out of the cartridge allowing the spring bungee to extend beyond its normal travel and jam. When this occurs the servo valve will be so placed as to direct hydraulic pressure to one side of the actuating cylinder forcing the ailerons to their full travel. The linkage would be thrown out of adjustment and the pilot would be unable to move the stick to apply opposite aileron.

The Hazard

It could not be definitely determined whether the cartridge was incorrectly assembled or whether the circlip did not withstand repeated use. Nevertheless, it would appear that the use of circlips in such a manner in critical controls is not a good practice.

The Fix

The fix in this case was to redesign the cartridge replacing the circlip with a cap which screws on.

PRECEPT 4.

Parts or components of the aircraft other than basic structure should be designed to fail with safety. This means that failure will not create additional or cumulative hazards.

The Situation

While at a high altitude the pilot of a single engine aircraft experienced an engine seizure. The pilot set up his forced landing procedure heading for the nearest suitable aerodrome which was some distance away. The pilot arrived over the field without further difficulty. During his final approach to the field, control of the aircraft was lost and the aircraft crashed.

This particular type of aircraft is fitted with power controls using hydraulic pressure supplied by an engine driven pump or alternatively in the case of emergency by an electrically driven pump. In the case of engine seizure the battery is the only source of electricity to drive the pump and control of the aircraft can be maintained only so long as there is life in the battery. The life remaining in the battery depends on many variable factors and hence we have a situation in which an engine seizure may culminate in the pilot being unable to actuate the flying control surfaces.

Investigation

As the battery was destroyed in the crash, investigators were unable to prove that the battery had lost its charge prior to impact. Nevertheless, there was some evidence to suggest that this was the case.

The Hazard

The hazard in this design is that an engine seizure may culminate in the pilot being unable to control the flight of the aircraft.

The Fix

Emergency flight control systems must be made independent of electrical or hydraulic power sources.

CONCLUSION

In conclusion I would request that my observations be not taken as being critical of the aeronautical engineers who designed our magnificent aircraft. They are without doubt amazingly skilful, resourceful and competent men. Despite their foresight, their past experience with older types of aircraft and extensive prototype testing of a new type, it must be expected that some design weaknesses may become evident only after the aircraft has been in use for some time. *It is paramount in the interest of safety that once errors have been revealed and a fix established they should never be permitted to reappear again in a later design of any type of aircraft.* It may be appropriate to suggest here that many share in the responsibility for safe design. They include those who set the operational requirement, prepare the design specifications and monitor the mock-up and prototype trials. As the performance of our aircraft increases so do the penalties we pay for unsafe features. All of us who are concerned must give our utmost attention to the demands for safety. Learning from the mistakes of others is the least that can be done.

LEAD PENCIL ETCHING ON PROPELLER BLADES

The following is an extract from Canadian Pacific Air Lines' information bulletin Wing Tips.

A PROPELLER blade on one of our DC-6B Aircraft was found to have lines of corrosion on the aft (camber) side. On closer investigation it was apparent that the corrosion resulted from someone sketching or "doodling" with a lead pencil on the aluminum surface.

Propeller blades are aluminum alloy; a lead pencil is essentially carbon. Aided by the presence of water, electrolytic corrosion takes place between the carbon and aluminum, in this case etching lines about ⅛" wide.

This corrosion was not deep, nor would it be likely to progress to any dangerous stage. However, it does take some time and effort to sand out. All personnel, therefore, are requested to avoid writing with a lead pencil on propeller blades or any other aluminum surface, and if any such writing or marking is found, to remove same before the aircraft goes into service.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute

will be held in the

SHERATON-MOUNT ROYAL HOTEL
MONTREAL

on the

3rd and 4th May, 1956

The Programme, which will include Sessions on

Propulsion, Manufacturing, Design, Maintenance, Aerodynamics

as well as the annual Business Meeting,

is now being prepared.

This meeting affords an opportunity for the presentation of papers by members of the C.A.I. The Council is most anxious to encourage Canadian papers and hopes that any member wishing to contribute to any of the above-mentioned Sessions, will submit a summary of his paper for consideration. Such summaries must be in the hands of the Secretary by the 31st January 1956.

C.A.I. LOG

SECRETARY'S LETTER

EDUCATION AND TRAINING

I THINK that it is time that we said something about the Institute's activities in connection with Education and Training. Quite a lot has been going on and hardly any of our members are aware of it.

As everyone knows there is a perennial complaint about the shortage of trained manpower in the industry and the habit of going to Great Britain and the U.S.A. to find men qualified for the senior positions. Last May the Institute set up a Committee for the purpose of examining the whole question, firstly to determine whether the complaints were well founded and the extent, if any, to which the education and training in this country was failing to meet the demand, and secondly to recommend ways and means by which the C.A.I. could help. It was recognized that this was no problem which could be solved overnight and that no useful purpose would be served by a quick glance around the industry and airlines, and the impetuous establishment of a few scholarships.

The Committee consisted of Professor T. R. Loudon, Air Vice Marshal E. W. Stedman and Mr. R. H. Guthrie. Professor Loudon was appointed Chairman and the Committee was told to recommend the appointment of other members as the need arose. I was asked to act as Secretary to the Committee for the time being.

During the past few months, the Committee has been busy preparing a Questionnaire. It was realized that nothing could be done without some statistics and other information which would define the problem, and this data could only be obtained from the organizations using aeronautical manpower. And so a detailed and searching Questionnaire has been prepared and it has just been sent out to all Sustaining Members, to several other Companies, to the Armed Services and Government Establishments and Departments. The Committee has been guided by the Department of Labour in some of the fine points of questionnaire-drafting and the Department has consented to help the Institute in the tabulation and analysis of the results. One feature of the procedure is that all returns are anonymous and, by the use of a code, only the members of the Committee will know which organization made any particular return.

It will require a good deal of time and effort to complete one of these Questionnaires properly but the indications are that those who have been asked to make this contribution are enthusiastically trying to do their share. Such cooperation is essential if the Committee is to reach any useful conclusions and it is gratifying to find that the enquiry is being taken very seriously by all concerned.

This is one of the Institute's major projects and it may have far-reaching results. The immediate results will not be spectacular but I will try to keep you informed of each little step forward.

NEW YEAR RESOLUTIONS

In the Editorial of the January 1955 issue of the old C.A.I. Log, I outlined the work for the year as follows:—

> "This C.A.I. Log must blossom into a useful Journal; . . . . . The problem of the training of aeronautical engineering manpower must be studied by the C.A.I.; . . . . . Additional Branches must be set up . . . . . And the C.A.I. must find ways to serve the scattered Air Engineers, students and others who are not readily reached through the normal Branch channels."

We have made a start on the first three and we have done a lot of thinking about the last. But in 1956 we must do something effective about the last. Any suggestions?

BRANCHES

BRANCH PROGRAMMES

THE following particulars of Branch programmes for the second half of the season have been received to date:

Ottawa

11 JANUARY
"*The Training of an Engineer*"
Professor T. R. Loudon

8 FEBRUARY
"*Naval Aircraft Carrier Operations*"
Speakers from the R.C.N.

14 MARCH
"*Modern Landing-gear Design*"
Speaker from Bendix Aviation Corporation

11 APRIL
"*Some Characteristics of Human Performance in Flying Operations*"
Dr. M. G. Whillans

9 MAY
"*Principles of Automatic Navigation*"
W/C J. G. Wright

Winnipeg

31 JANUARY
"*Production*"
T. V. Chandler

28 FEBRUARY
"*Calculating Machines*"
Speaker from Computing Devices

26 MARCH
"*Helicopters*"
Speaker from Bristol Aeroplane Co., England.

30 APRIL
Annual General Meeting

Vancouver

16 JANUARY
Joint SAE/CAI Dinner Meeting
"*The Convair V.T.O. Aircraft*"
J. Donaldson

15 FEBRUARY
"*Maintenance and Operational Problems of Helicopters*"
A. Stringer

15 MARCH
"*The Britannia*"
Speaker from Bristol Aeroplane Co.

20 APRIL
Annual General Meeting

15 MAY
"*The Transistor*"
P. C. Kenney and T. H. Corbett

Montreal

18 JANUARY
"*Recent developments in acrylic aircraft glazing materials*"
W. Farr

15 FEBRUARY
"*Aeroelasticity*"
D. Bogdanoff

21 MARCH
Plant Tour

18 APRIL
(*Subject undecided*)
Dr. D. C. MacPhail

NEWS

Vancouver—Reported by R. J. McWilliams

Social Evening

Although held in mid-week, with the weatherman predicting a snow storm, seventy members and their wives and guests turned out for the Fall Get-Together which was held on the 15th November in the Canyon Gardens. With Smorgasbord, dancing and gossip, it proved a very enjoyable evening.

November Meeting

Fifty-one members and guests gathered at the Aero Club of B.C. for the monthly meeting on the 22nd November. What business we had was dealt with in the record time of fifteen minutes, when we broke off to "tank up", prior to getting down to the main purpose of the meeting, at 8.30.

The Chairman asked Mr. R. J. McWilliams to introduce the Speaker for the evening, Mr. D. Strachan, Senior Forecaster, D.O.T. Met. Office, and his subject "Flying the Jet Stream".

Mr. Strachan outlined the relatively short history of the jet stream and gave a brief discussion of the relationships between pressure forces and wind movements. The coriolis effect and the nature of geostrophic and gradient winds were mentioned briefly. The "thermal wind effect" of temperature gradients in the upper atmosphere was demonstrated. Finally to conclude the basic physics behind the distribution of pressure, and hence of wind movement aloft, the average state of the troposphere, the stratosphere and the tropopause was defined with particular reference to the reversal of the latitudinal temperature gradient at high levels.

Various theories of the general circulation were mentioned since it was emphasized that the jet stream had no real meaning except as it pertained to this circulation. It was shown that the first theories of global circulation were required to explain only a limited amount of surface observation but that as each new exploration of the upper atmosphere was achieved, the original hypotheses had to be amended or abandoned. The more recent theories of Bergeron and Rossby were sketched and attention was drawn to the indirect circulation of the midlatitude cell, and the relationship of that cell to the cyclones and anticyclones of the westerlies. It was further pointed out that a major task of theoretical meteorologists during the next few years would be the assimilation of the jet stream into the mechanism of the general circulation.

The difficulties confronting this assimilation were spoken of, particularly the scarcity of information about many of the major processes that effected transfer of energy in the atmosphere. It was stated that even if complete mathematical solution of the equations was not feasible, some progress toward a reasonable description of global atmospheric motion could be made if the principles of the conservation of absolute angular momentum and of absolute vorticity were applied to the problem. Qualitative statements concerning the "sources" and "sinks" of these observables were made, and it was shown that some of the properties of jet streams were compatible with the fluxes of momentum and of vorticity that are approximated in the atmosphere.

The actual structure of an average jet stream was then discussed and features of the cross-sectional diagrams derived by Palmen and associates were pointed out. The characteristic properties of the jet stream were mentioned in general fashion, always from the point of view of their constancy. In particular the seasonal changes in latitude, altitude, and velocity were mentioned, the existence of short-lived regional jets was emphasized, and the life cycle of a hemi-

spheric jet stream was sketched quite briefly.

The operational aspects of flight in or near the jet stream were then considered. The findings of Pan-American meteorologists in the Western Pacific, of BOAC personnel connected with high level Comet Flight in Europe and of the scientists connected with Project Jet Stream in the U.S. were dealt with. In particular the possibility of associating particular cloud forms with the existence of jet streams was discussed, the degree and location of turbulence was considered, and the increasing knowledge of the micro structure of the jet indicated particularly with reference to the existence of wind streaks within the general framework of the jet. Speculation was made that these streaks might be associated with areas of major turbulence at high levels.

Once again the talk was followed by the "jam session" type of discussion period. Since there were a number of flying types present, the discussion tended toward the Pacific Jet Stream. Mr. Strachan attempted an estimate of the assistance that might be expected in the Pacific Area. It was shown that the help that could reasonably be expected in parts of the Pacific would be of a sporadic nature due to the shorter life of the regional jets. In contrast, it was shown that in other parts of the world the jet stream showed a constancy that made special flight planning worthwhile.

The meeting terminated at 10.30 p.m., the thanks of the members being expressed by Mr. J. R. Parbery.

December Meeting

The dinner meeting held on December 13th was attended by sixty-eight members and guests, and was preceded by cocktails. It should be explained that we arranged a Christmas raffle. The proceeds paid for the prize and for the cocktails. We drew for the door prize and the winner was presented with his door, sans pane. We had a draw for "A Chicken Dinner for Two" also. The winner was handed an irate, voluble, and very much alive pullet. The producer of these hilarious doings, was our ubiquitous Programme Chairman, Mr. Gordon Ades.

The dinner was followed by a very short business section, the main item of business being the election of the Nominations Committee for the 1956 elections.

After an additional twenty or so members and guests had arrived and seated themselves, Mr. I. A. Gray introduced our first speaker, Mr. B. W. Torell, Superintendent of Engineering, T.C.A., and his talk, "The Vickers Viscount".

A brief description of the reasons why the Viscount was chosen, was followed by a comprehensive review of the leading particulars of the aircraft, and of the various systems. Various items were of particular interest; the single spar wing structure; the preheating of fuel to prevent icing in the micro-filter; the crash emergency system; and the various types of de-icer systems. A description of the operational aspects laid emphasis on the reduction of cockpit functions. Compared with other aircraft operated by T.C.A., the Viscount has roughly half the functions of the Super Connie, and approximately two-thirds of those of the North Star. T.C.A. experience from the maintenance point of view was dealt with quite extensively. Charts covering maintenance delays, feathering experience, and off scheduled engine changes proved enlightening, and spoke favourably of the reliability of the aircraft. One couldn't help but admire the ability of T.C.A. to produce such detailed statistics.

Mr. Torell's talk was followed by a short film of the aircraft, produced by the manufacturer.

Our second speaker, Mr. E. Gerber, Service Representative, Rolls-Royce, and his subject, "The Dart Engine", were then introduced.

Mr. Gerber's talk dealt with the development and service problems encountered. The thoroughness of the manufacturer and the vigorous test-programme from 1945 until 1949 was most impressive and enlightening. The various design methods employed to increase the output of the engine are nothing short of admirable. The modification of the passages between the first and second compressors, the elimination of gas leaks, the investigation of temperatures and pressure in both the compressors and the combustion chambers, and the shrouding of the turbine nozzle guide vanes, all contributed to a very appreciable increase in shaft - horse power.

The design and development of the reduction gear, and the control mechanism were dealt with quite extensively. With the use of an excellent set of slides Mr. Gerber was able to give a detailed description of the engine from the propeller to the exhaust nozzle. The combined use of slides and cut-aways of various components illustrated the various design changes and modifications.

The latter portion of the talk was devoted to the safety aspect of engine operation. Failure of major components was dealt with item by item, and the various safety features described, with emphasis on the fail-safe devices.

From an original design rating of 1,000 shp the engine has been developed to 1,600 shp. The overhaul period has increased from 400 to 1,050 hours. Future development will concentrate on improved reliability and a longer overhaul life.

A short discussion period followed and our appreciation was expressed by Mr. A. T. Gilmour, T.C.A., Vancouver.

Thus ended a most enjoyable and informative evening. We shut up shop at 11.15 p.m.

Ottawa—Reported by Dr. A. Jaworski

December Meeting

On Wednesday, December 14, 1955, the Canadian Aeronautical Institute, Ottawa Branch, held a meeting at the Beaver Barracks, with G/C D. M. Holman, Vice-Chairman of the Branch, acting as Chairman, and Mr. C. E. B. McConachie, Technical Assistant to the Director of Operations, Canadian Pacific Air Lines, as guest speaker of the evening. The Chairman pointed out that the announcements of the meeting were sent late, because the printers had a Christmas rush. In spite of this fact, and that several Christmas parties were already planned, about forty members turned out.

The Chairman called on Mr. C. D. Long, who is in charge of the Program Committee, to tell briefly about the future program.

The speaker was then introduced by Dr. D. A. McDougall, a personal friend of his for many years, and the paper was presented under the title "Airline Operation of Long-Range Aircraft".

The sound of Mr. McConachie's voice only occasionally stitched its way across the dark cloth of blackboard, which he covered continuously with graphs and equations. Therefore, until his very interesting paper is published by the Journal, the present summary which, of course, must skip over the graphs and equations, is definitely a poor "ersatz".

It started in a simple way; the basic equation for power requirement in flight, but it ended up with intricate instructions for the pilot to get maximum payload on DC-6 flights from Mexico City, where the airport, due to its high altitude and high temperature, is a challenge for any operator, especially when the necessary safety precautions about aircraft's loadings are accounted for. The pilots on these flights are following the constant power procedure, which is much easier to implement than the constant air-speed flying. And the zig-zag approach, in practice, to the ideal curve of constant power is already so close that no further significant gains could be anticipated. It might be recalled that the Super-Constellation on its flights in Canada is also following the constant

power procedure, and only on the flights over the North Atlantic, when the flying time is over eleven hours, is it worth while to switch over to constant speed flying in order to save fuel.

Bearing in mind that the dependence of a.m.p.g. is on three factors:

(a) the drag of the airframe,
(b) the efficiency of the power plant,
(c) the efficiency of the propeller,

it was underlined by the speaker that it is impossible to get the maximum efficiency of each of these factors simultaneously and, therefore, a compromise is unavoidable. Furthermore, it is highly desirable that the aircraft's efficiency should not be adversely affected by different lengths of the hops.

There are several airports which are enjoying long approaches with no obstacles at all. This being so, the insistence on the 50 foot obstacle rule imposes an unnecessary burden on the operator at such places, especially in the jet area, as this type of engine has relatively less power reserve for take-off and is significantly affected by the high ambient temperature. However, up-to-date information about newly erected obstacles is still lacking.

The speaker ended up with a plea to the engineers for an efficient heat exchanger, which definitely will pay its way for a very long range aircraft.

It may be recalled that Mr. A. E. Russell of the Bristol Aeroplane Company, in the 1949 Wright Brothers lecture has made a similar suggestion by saying that the exhaust heat energy may be recuperated by means of a heat exchanger and fed back into the cycle, with significant savings on fuel if the termal ratios of the regenerative matrix are close to 90 per cent.

After Mr. McConachie's address, a film was shown illustrating the different phases of the C.P.A.L. activities. A question period was then started about jet streams and navigational instrumentation for the Polar flights. It was pointed out by the speaker that both these topics are very important to the operators, but more records are required about the jet stream before a full benefit could be taken of this event in scheduled timetables.

W/C W. J. Grant thanked the speaker in the name of all those present and the meeting adjourned at 10.15 p.m.

Winnipeg—Reported by N. D. Brewer

November Meeting

At the meeting held on the 29th November, the speaker, Mr. J. H. Parkin of the National Research Council of Canada, was introduced by J. J. Eden, the Vice-Chairman of the Branch, who, in his introductory remarks, mentioned the highlights of the IAS/CAI meeting of this fall, the W. Rupert Turnbull Lecture, which Mr. Parkin gave, and the visit to the National Aeronautical Establishment of which Mr. Parkin is Director.

Mr. Parkin first discussed the organization of the "Honorary Advisory Council for Industrial and Scientific Research" pointing out its uniqueness in that it is under a committee of Ministers of the Government and hence is not just another branch of the Civil Service. Thus the Council is very flexible in its operation. This is necessary since the Council may be called upon for advice on any matter. The advisory nature was stressed, i.e. the optimum course of action to be taken upon a matter will be given by the Council but it is not their responsibility to implement these recommendations.

Thus it is seen that the activities of the N.R.C. must cover many fields and many sciences. The laboratories are set up as Research Divisions under four headings: Engineering, Building Research, Radio, and Mechanical Engineering, the latter being approximately 80% aeronautical.

The remainder of the talk was devoted to the Mechanical Engineering Division.

The selection and employment of scientific staff is particularly difficult since top calibre people are required and only about 1% of university graduates are of a research turn of mind. In addition, there is stiff competition for these people due to industrial demand. Team effort is required and here temperament plays a part. Thus, there sometimes is a fairly high turnover of staff.

The talk was illustrated by slides showing the laboratories and the facilities.

In the following discussion it was pointed out that much of the work done is of an investigatory and developmental character, primarily for the services and only a little pure research is done. There is also a considerable amount of testing of materials for the services (particularly AMC), and other Government departments. Little of this type of work is done for industry except when commercial laboratories do not have the facilities for a particular problem.

The evening ended with a film on the N.R.C. Ship Laboratory.

C. M. Hovey thanked the speaker.

Social Evening

A social meeting was held on the evening of 2nd December 1955 in the Albany Room of the Assiniboine Hotel when, for the first time, the members' wives met with the members themselves. (*A hitherto unpublished advantage of C.A.I. membership—Sec.*) This meeting consisted of a dinner and a dance and the affair was a definite success. The refreshments were generously donated by one of our Sustaining Member companies. J. J. Eden, our Vice-Chairman, was in the chair.

SUSTAINING MEMBERS

NEW SUSTAINING MEMBER

THE following Company has joined the Institute as a Sustaining Member:

Okanagan Helicopters Limited

NEWS

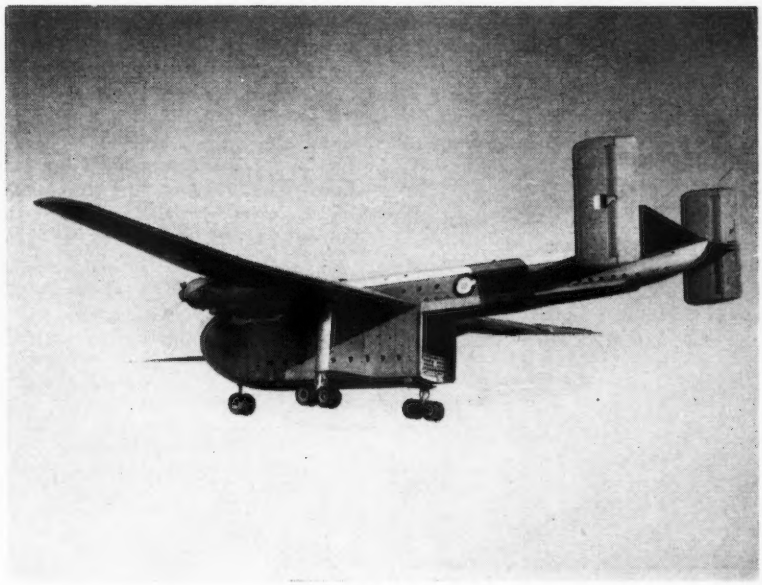
Canadian Aviation Electronics Ltd. announces that work has started on their new 16,000 sq. ft. plant in Vancouver and the building is expected to be completed in the spring of 1956. The plant will house the engineering, manufacturing, repair and overhaul and consumer products division of C.A.E.'s West Coast Branch.

In a further development of its activities C.A.E. recently concluded an agreement with the Allen B. Du Mont Laboratories in the United States which allows C.A.E. to occupy the foremost position in the electronic patent field in Canada. According to the agreement, C.A.E. has acquired the control of all Du Mont Canadian patents, covering the manufacture and sale in Canada of cathode ray tubes, television sets, transmitters and other electronic instruments.

Under the new arrangements, C.A.E. has enlarged its previous relationship with the Allen B. Du Mont Laboratories. As a result C.A.E. has a particularly strong patent position in the field of radar, television and special electronic devices. It is to Dr. Allen B. Du Mont that the electronics industry owes the development of the cathode ray tube in a commercially usable form. The cathode ray tube is the basic element in almost all modern electronic devices. Dr. Allen B. Du Mont also pioneered in radar and related fields as a consequence of his cathode ray tube work.

The patents on developments of C.A.E. will be added to C.A.E.'s Canadian Du Mont portfolio. Canadian Aviation Electronics Limited is prepared to license all Canadian electronic enterprises to operate under the Du Mont and C.A.E. patents.

Field Aviation Co., Ltd., representing Blackburn & General Aircraft Ltd., England, has given a few particulars of the Blackburn Beverley which was recently brought to Canada from England for winterization trials for the British Ministry of Supply. It was flown over by the R.C.A.F.



Blackburn Beverley

In the R.A.F. the aircraft is used for transport duties and as a paratroop carrier. In Canada it would be particularly well adapted for supplying by air all types of fuel and other items to Arctic stations which are only open by sea at the most one month a year. At the recent meeting of the Canadian Aeronautical Institute in Ottawa, the Rt. Hon. C. D. Howe, Minister of Defence Production, noted the need for such an aircraft in Canada.

The aircraft has a maximum payload of 22 tons carried in a low-slung boxlike hold measuring 40 feet long by 10 feet by 10 feet. This is adequate for a Greyhound bus which could enter through the enormous doors at the back up a build-in floorboard ramp. Alternatively it could carry 160 passengers or a combination of 42 passengers, their personal luggage, three automobiles and 12 tons of freight.

As by far one of the largest aircraft to appear in Canada, the Beverley will usher in a new era in air freight. Its wingspan is 162 feet; its length 99 feet; and height 33 feet. By comparison, the TCA Super Constellation has a span of 123 feet, the North Star 117 feet, the Viscount 94 feet, the Bristol freighter 108 feet and the wartime Lancaster bomber 102 feet.

Despite its size and loaded weight, the Beverley can get airborne in 1,000 yards from a grass field and land in even less distance. It can carry its full payload for 1,000 miles in still air and can do 2,000 miles with a very useful load.

After its Atlantic flight, the Beverley will be demonstrated to the RCAF and northern operators at Montreal, Ottawa and Toronto before it proceeds to Edmonton.

Canadair Ltd. held an "Open House" of their Test and Development Laboratories on December 1st 1955 for a group of officials representing technical departments of the government and the services. Canadair's guests were welcomed by Mr. J. G. Notman, President, and Mr. W. K. Ebel, Vice-President, Engineering, and were then split up in small groups who under efficient leadership of Canadair's guides proceeded to visit seven laboratories.

The visit was not a mere walk through the vast new experimental facilities of Canadair, but consisted of skilfully arranged demonstrations in each laboratory, introduced by comprehensive technical comments from Canadair's engineers.

In the Special Weapons Laboratory the design and operation of the hydraulic

control system of the Velvet Glove missile were shown. A missile was "flown" by means of an electronic flight simulator, with which the operational performance of the complete missile system or of its components can be investigated.

In the Electronic Standards Laboratory calibration and evaluation procedures were demonstrated including determination of the properties of the dielectric used on CL-28 fin antenna. While listening to a variable frequency generator the visitors were able to determine the upper limits of their response to sound and, therefore, the individual requirements of their hi-fi music systems!

The loading of a guided missile fin due to aeroelastic effects was explained and demonstrated in the Structural Components and Dynamic Tests Laboratories. Resonance tests of a guided missile wing using sonic excitation were carried out; an electro-magnetic vibrator was used in resonance tests of an entire missile.

The Structural Test Laboratory is equipped with three large machines of German manufacture (Losenhausenwerk) designed to Canadair suggestions. The largest machine is for static tension and compression testing to a maximum load of 400,000 lb. The other two machines are for static/dynamic testing and have a dynamic capacity up to 120,000 lb. from 400 to 3,000 cycles per minute.

In the Experimental and Flight Test Laboratories investigation of low temperature effects on a hydraulic mock-up system using an environmental chamber was shown. In the Conrad environmental chamber conditions up to 80,000 ft. altitude and from -125°F. to 250°F. temperature can be simulated.

The Materials and Process Laboratories and the Mock-up Site were also visited. In the latter an elaborate wind tunnel model of the CL-28 Maritime Reconnaissance aircraft tested in th NAE low speed wind tunnel in Ottaw was shown and the full-scale wooden mock-up of the CL-28 inspected. The variety and complexity of special equipment carried in this aircraft could be appreciated. The CL-41 basic trainer cockpit mock-up was also shown.

All in all, the visit was a most interesting one and technically worthwhile. It certainly left the impression that, as Mr. Ebel said in his welcoming address, Canadair Ltd. are not merely building aircraft under license but are actually also engaged in extensive development programmes supported by diversified experimental and test facilities.

MacDonald Bros. Aircraft Ltd. has announced that with effect from the 1st January 1956 the general business of the Company will be carried on by **Bristol Aircraft (Western) Ltd.**

MEMBERS

LIST OF MEMBERS

THE preparation of the List of Members was put in hand on the 5th December, when the cards recently distributed to members had been returned and assembled. It is hoped that the List will be available before the end of January. A copy will be sent to each member of the Institute.

In future, particulars of new members will be listed in the Journal, as they are admitted. The first such list appears below.

ADMISSIONS

At a meeting of the Executive Committee of the Council, held on the 9th December, 1955, the following were admitted to the grades of membership shown.

Associate Fellow

D. J. Caple (on transfer from Member)

V. E. Crompton (on transfer from Member)

Dr. G. S. Farnham, Asst. Manager, Development & Research, International Nickel Co. of Canada Ltd., 25 King St. W., Toronto 1, Ont.

Member

Miss M. M. Callan, Asst. Research Officer, National Research Council, Aerodynamics Section, Ottawa: *451 MacArthur Rd., Ottawa, Ont.*

J. Carruthers, Mechanical Systems Eng'r, T.C.A., Montreal Airport: *95 St. Joseph Blvd., Apt. 11, Dorval, P.Q.*

R. W. F. Crawley, Design Eng'r, Jarry Hydraulics: *1540 Elizabeth St., Apt. 1, Ville St. Laurent, P.Q.*

S/L R. S. Crosby, Sr. Development Eng'r, A/C, Avro Aircraft Ltd.: *78 West Hampton Drive, Weston, Ont.*

J. H. Davis, European Representative, Canadair Ltd.: *56 Warwick Square, London S.W. 1, England.*

F/O M. C. deMaurivez, Air Defence Command Headquarters: *P.O. Box 118, R.C.A.F. Stn., St. Hubert, P.Q.*

W. N. Farrance, Sr. Design Eng'r, Avro Aircraft Ltd.: *14 Crestview Ave., Brampton, Ont.*

H. C. Hamilton, Methods Eng'r, De Havilland Aircraft of Canada Ltd.: *25 Fieldway Rd., Toronto 18, Ont.*

A. E. Hughes, Inspection Representative, Avro Aircraft Ltd.: *112 Riverbend Crescent, Winnipeg 12, Man.*

L. Lloyd-Davies, President & Chief Eng'r. L. Lloyd Davies & Associates, Montreal Airport, Dorval, P.Q.

Dr. P. Mandl, National Aeronautical Establishment, Ottawa: *162 Camelia St., Ottawa, Ont.*

Dr. P. Marvin, Consultant, American Viscose Corporation, 1617 Pennsylvania Blvd., Philadelphia 3, Pa.

F/L E. G. D. Maynard, DIE Eng. 2-2, Air Force Headquarters, Ottawa: *R.R. No. 1, Cumberland, Ont.*

R. N. McCollum, District Manager, Sperry Gyroscope Co. of Canada Ltd., Vancouver: *1505 West Pender St., Vancouver, B.C.*

G. F. Nelson, Methods-Foreman, Canadair Ltd.: *6991 St. Denis St., Montreal 10, P.Q.*

G. E. Pawson, Group Leader, Engineering, Canadair Ltd.: *216 Castlefield Ave., Dorval, P.Q.*

J. Pogson, Liaison Eng'r, S & S, Canadair Ltd.: *P.O. Box 374, Hudson, P.Q.*

R. H. Poole, Designer, Avro Aircraft Ltd.: *Box 165, Malton P.O., Ont.*

F. Ritchie, Sr. Test Eng'r, Jarry Hydraulics: *1540 Elizabeth, Apt. 1, Ville St. Laurent, P.Q.*

B. K. Ryan, Eng'r, Canadair Ltd.: *c/o 335 St . Aubin St., Ville St. Laurent, P.Q.*

J. Schwartzman, Canadair Ltd.: *5790 Darlington Ave., Apt. 6, Montreal, P.Q.*

A M Scott, Sales Manager (Aero.), Rolls-Royce of Canada Ltd., P.O. Box 10, Dorval Station, P.Q.

G. J. Sobolewski, Group Leader, Canadair Ltd.: *R.R. No. 1, Ste. Dorothee, P.Q.*

D. O. Stapleton, Group Leader, Canadair Ltd.: *58 Cloverdale Ave., Dorval, P.Q.*

J. D. G. Stevenson, *3500 Ridgewood Ave., Apt. 103, Montreal 29, P.Q.*

H. S. Walker, Inspector, Class A, Enamel & Heating Products, Ltd., A/C Div.: *R.R. No. 6, Amherst, N.S.*

Members (cont.)

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NEWS

D. C. Smith, A.F.C.A.I., formerly Head of the Technical Department of the R.Ae.S. has been appointed Executive of the Structures and Material Panel of A.G.A.R.D., in Paris.

R. Carter Guest, M.C.A.I. has retired as Councillor for the Winnipeg Branch and Chairman of the Branch Membership Committee and has gone to Vancouver.

A. E. Hughes, M.C.A.I. of Avro Aircraft Ltd., who has been serving on temporary duty at MacDonald Bros. Aircraft Ltd., has now returned to Malton.

F. J. New, M.C.A.I., of Avro Aircraft Ltd., has been transferred to Ottawa for duty with A.M.C., R.C.A.F. Rockcliffe.

LCDR. J. A. Nicas, M.C.A.I., formerly Supervisor of Engineering for Canadian Pacific Air Lines (Repairs) at Calgary, Alberta, has been appointed Staff Officer General Engineering on the Staff of the Directorate of Air Engineering at Naval Headquarters, Ottawa, Ontario. LCDR. Nicas took up his new assignment in early November.

R. C. Smith, M.C.A.I. of the Winnipeg Branch, has been appointed to fill the vacancy on the Council caused by Mr. Guest's retirement from office.

H. J. T. Young, M.C.A.I., formerly with Avro Aircraft Ltd., has taken a position as a Surveyor with the Air Registration Board in England. He is at present engaged in the Flight Test Section and working on the Comet.

NEWS (cont.)

M. I. Barron, Technical Member, has left Northwest Industries Ltd. and transferred, as an Air Engineer, to the Chilliwack Flying Club, Chilliwack, B.C.

J. E. Fox, Technical Member, has severed his connection with Saunders-Roe Ltd., Isle of Wight, and has taken a position as Design Engineer with the Lockheed Aircraft Corporation (Georgia Division), Marietta.

E. D. Jones, Technical Member, formerly of Toronto has moved to Ottawa to take an appointment as aircraft technician with the Department of National Defence.

W. B. Miller, Technical Member, of Trans-Canada Air Lines has been transferred from Winnipeg to Malton.

MEMBERSHIP OF THE C.A.I.

as at the 31st December 1955

Technical	**1352**
Associates	**56**
Total	**1408**

The Technical grades comprise the following:

Honorary Fellows	10
Fellows	18
Associate Fellows	174
Members	679
Technical Members	363
Technicians	31
Students	77

McCURDY AWARD

The McCurdy Award will be presented at the Annual General Meeting on the 3rd - 4th May, 1956.

It is presented each year

To A Resident of Canada,

For Achievement in design, manufacture or maintenance related to aeronautics.

NOMINATIONS ARE INVITED

Each nomination should include

(a) The name and affiliation of the nominee,

(b) Confirmation that he is a resident of Canada,

(c) A citation of the particular achievement for which the nomination is being put forward, and

(d) The name of the nominator.

The nominee need not be a member of the C.A.I. and the achievement need not have taken place within the last year, though it should be recent.

Nominations should be in the hands of the Secretary not later than the 12th March, on which date they will be handed over to the McCurdy Award Selection Committee.

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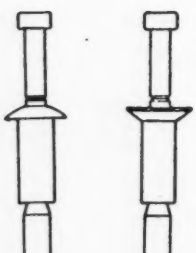

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